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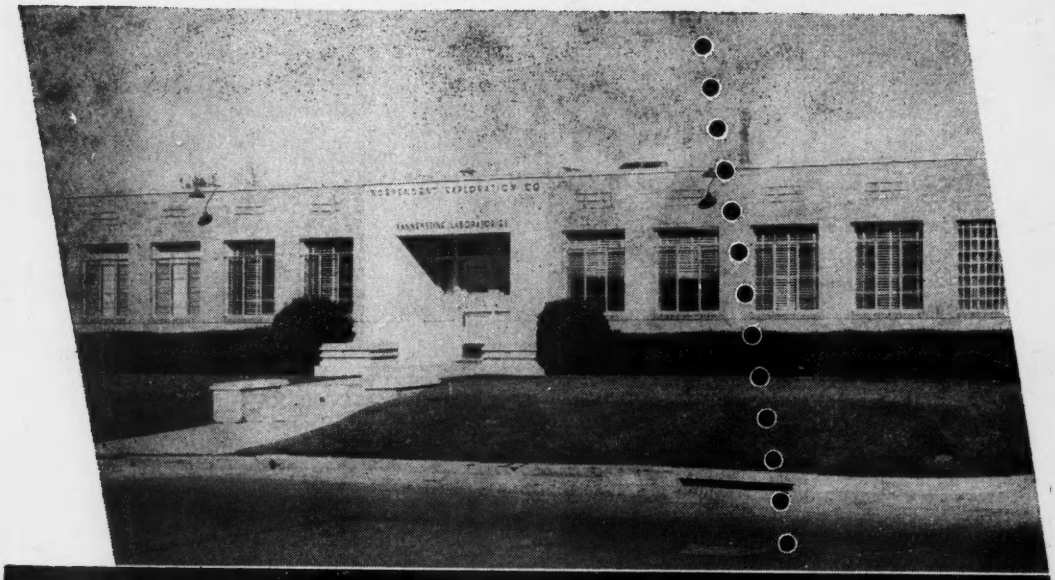

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GEOPHYSICS

A Journal of General and Applied Geophysics

AN INSTRUMENT FOR PLOTTING REFLECTION DATA ON THE ASSUMPTION OF LINEAR INCREASE OF VELOCITY*

JOHN W. DALY†

ABSTRACT

An instrument is described by means of which reflection data may be rapidly and accurately plotted in the case that the velocity is assumed to increase linearly with depth. Lengths corresponding to the radius of the wave-front circle and the depth of its center are obtained directly from observed reflection times by means of suitable scales attached to the device. Reflection data can be plotted either by dip units, or by the envelope method.

In many areas in which reflection seismology has been undertaken it has been found convenient and sufficiently accurate to assume that the velocity of the seismic wave increases linearly with depth as expressed by the equation

$$V = V_0 + kz, \tag{1}$$

where V_0 is the velocity at the surface, V that at depth z, and k a constant of proportionality. Both V_0 and k may have different values in different areas.

When the velocity varies according to equation (1), it is well known that both the wave trajectories of propagation of energy and the wave fronts in a vertical plane through the shot point are circular at any instant. Circular trajectory and wave-front charts offer a precise solution to reflection problems. Often, however, the scales of available charts are not suitable for some work, and the labor of constructing new charts for specific purposes may be prohibitive. To meet this difficulty an instrument was devised which would be applicable to a wide range of conditions and scales. As the instrument has been in use since 1938 and has proved to be of advantage in seismic interpretation, it is thought that a description of it may be of interest to practicing seismologists.

The problem to be solved from reflection data is the following: given a reflection profile along a line normal to the strike of dipping strata, and employing

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† Honolulu Oil Corporation, Lubbock, Texas.

The work on which the present paper is based was done while the author was employed by Shell Oil Company, Incorporated, and the paper is published with the permission of that Company.

a split spread also normal to the strike, to find the point in the two-dimensional vertical plane of the profile at which a given reflection occurs, and to determine the dip of the reflecting stratum at that point.

The conditions are illustrated in Figure 1. If a shot is fired at a point S at the surface, a spherical wave front will be generated whose section in the vertical plane of the profile is a circle. Let the radius of this circle be r' at time $t/2$ after firing the shot, and let the depth below the surface of the center of the

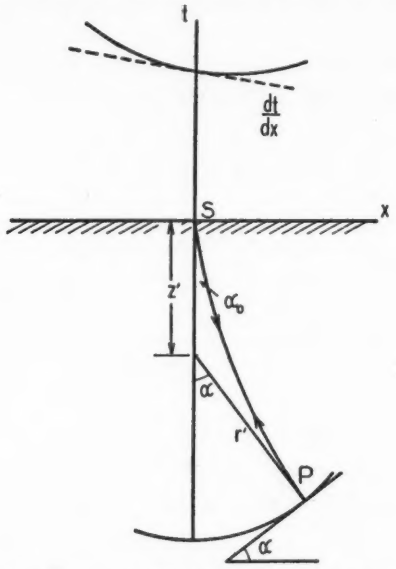

FIG. 1. Reflection from vertical incidence on stratum dip α for velocity increasing linearly with depth.

wave be z'. Since the reflection is recorded at the same point S at which the disturbance was generated, the wave must be normally incident at the reflection point P. The angle which r' makes with the vertical is therefore equal to the angle of dip α. Hence, provided we can evaluate the three quantities z', r', and α we can locate the reflection point P in the plane of the profile. These quantities may be obtained from previously known or observed data by means of equations familiar in seismic literature:

$$z' = \frac{V_0}{k}\left(\cosh\frac{kt}{2} - 1\right), \tag{2}$$

$$r' = \frac{V_0}{k}\cdot\sinh\frac{kt}{2}, \tag{3}$$

$$\tan\frac{\alpha}{2} = \tan\frac{\alpha_0}{2}\cdot e^{kt/2}. \tag{4}$$

In equation (4) α_0 is the angle of emergence at the surface of the reflection in question. It may readily be determined from the slope of the time-distance curve of the reflection in accordance with the relation,

$$\sin \alpha_0 = V_0 \cdot \frac{dt}{dx} \cdot$$

In practice, dt/dx is approximated by $\Delta t/\Delta x$, where Δx is the instrument spread and Δt is the difference in reflection times as observed at the ends of the spread.

Thus, if the initial velocity and the rate of increase of velocity are known, a

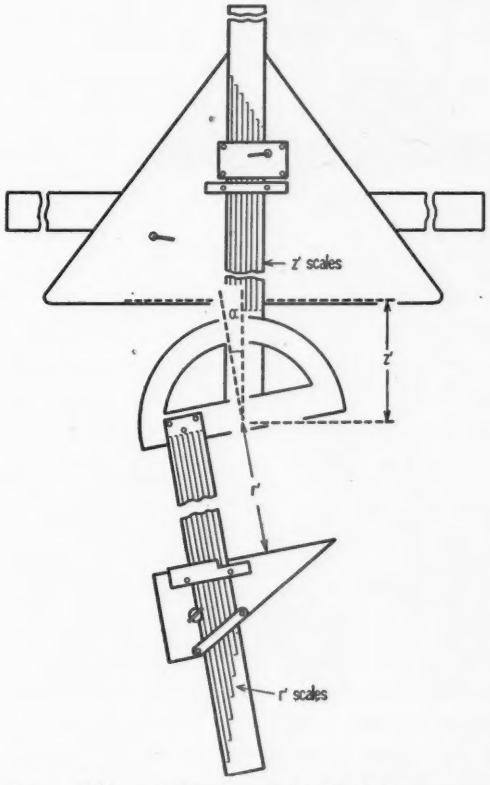

FIG. 2. Schematic drawing of plotting instrument.

pair of t-Δt values will define the reflection point P which can be located geometrically by two straight lines of known length, and an angle. The present instrument is designed to perform this operation in conjunction with a suitable t-Δt-α graph, or device for determining α.

The instrument is depicted in Figures 2 and 3; it consists essentially of two arms on which z'- and r'-scales are stamped, and a protractor. The scales are graduated to read directly in terms of time for given velocities. Each arm has

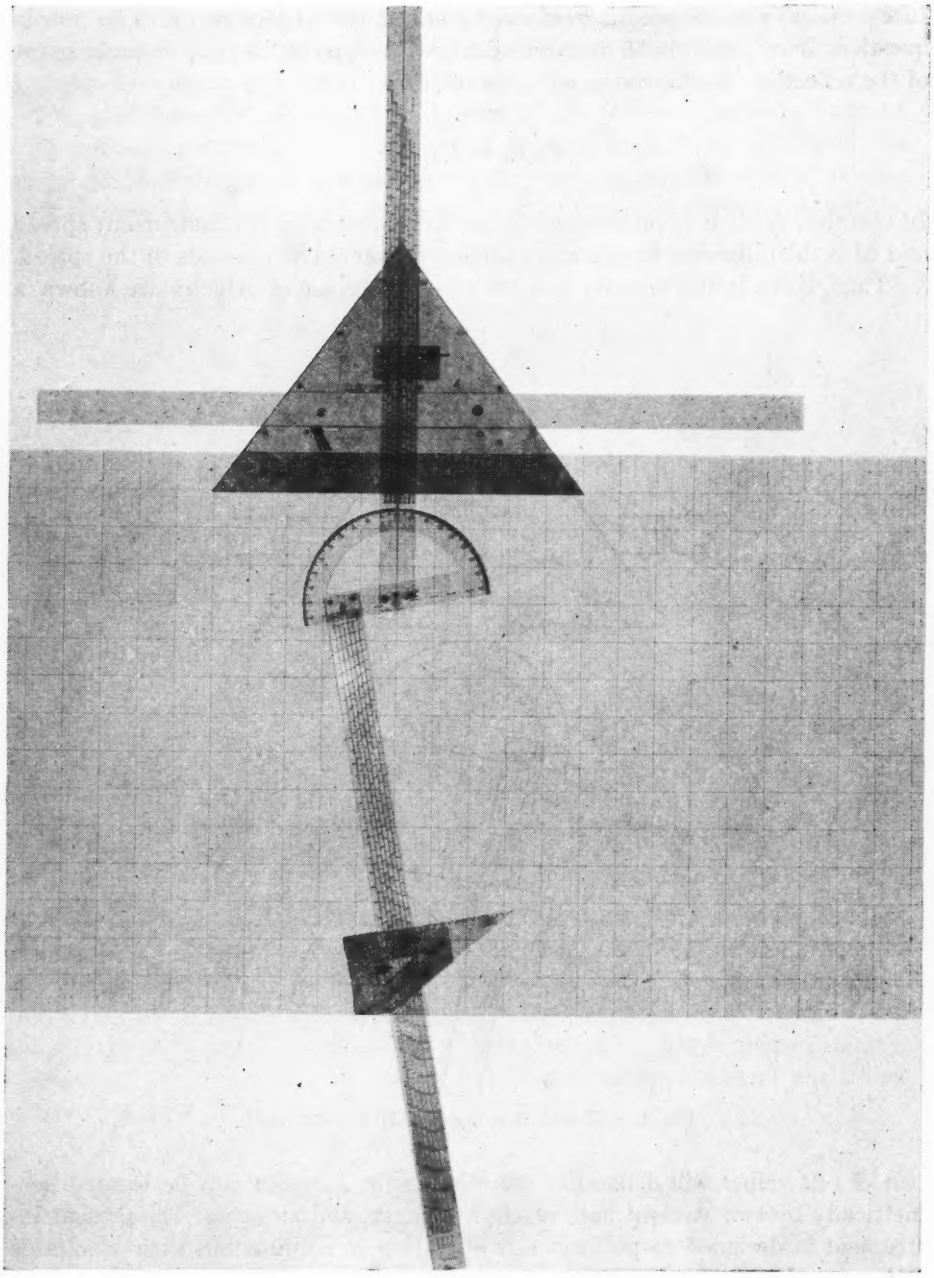

FIG. 3. Photograph of plotting instrument set for 10° dip.

seven appropriately labeled scales, each scale with the same rate of increase, but with different initial velocities. The arm bearing the z'-scales is free to move vertically in the head frame but it can be clamped in any desired position by the locking cam. The head frame is free to move horizontally on the guide bar and it, too, can be locked by a cam. At the lower end of the z'-scale arm the protractor is pivoted. The r'-scale arm is rigidly affixed to the protractor, normal to the base line, and offset from the center. The plotting triangle is free to move along the r'-scale so that the upper edge is always at right angles to it. This upper edge is graduated so that the zero point is the same distance from the r'-scale as is the pivot of the protractor. The triangle can be clamped in any position by means of a wing nut. To avoid reading the wrong scale, adjustable reading windows are provided. These are fixed so that only the desired scale can be seen but they can be adjusted quickly to another scale.

In practice, the section and horizontal guide bar are attached to the drawing board in such a way that the datum line on the head frame will be over the datum line on the section, as the head frame is moved along the guide bar. When the center line of the z'-scale is over the desired reference point, the head frame is clamped; the corrected t-value is read on the z'-scale and the scale clamped; then the same value is set on the r'-scale and the plotting triangle is clamped. If the value of α has already been determined from a suitable t-Δt-α curve, the r'-scale can be set at this angle from the vertical by means of the protractor. A line drawn along the top of the plotting triangle will then represent the reflecting bed at its proper position and true inclination. If a pencil is held at the zero point on the triangle and the r'-scale rotated, the pencil will trace the position of the wave front for that time. The envelope of a series of these wave fronts would represent the reflecting surface. Thus, by use of this device, reflection data can be plotted either by dip units, or by the envelope method.

The accompanying photograph (Fig. 3) is of one of these instruments set for a 10° dip at the time 2.400 seconds at a velocity $V_z = 6600 + 0.6z$.

The examples cited above are illustrative only of normal incidence. In the case of oblique incidence, the data may be plotted midway between the shotpoint and the instrument spread by making scales corrected for the time difference due to the offset of the instruments, or, a more practical method: the same scales may be used and the observed time values for oblique incidence transposed to time values at normal incidence, for equivalent depth, by means of curves. The necessary curves can be drawn quickly from wave-front charts. The approximation holds, with a high degree of accuracy, for ordinary dips.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the help of L. A. Martin in making the original design, and W. L. Hildebrand for his assistance in design and construction.

WAVE-FRONT CIRCLES FOR A LINEAR INCREASE OF VELOCITY WITH DEPTH*

F. A. VAN MELLE†

ABSTRACT

Formulas are derived which express the depths of the center of the wave-front circle and its radius as simple algebraic functions of known geometric quantities. By virtue of their simplicity, these formulas are readily applicable to the migration of reflections. While not intended to replace wave-front charts in areas of steep dip, they have proved their usefulness in areas of moderate dip.

The seismic properties of a medium in which the speed of propagation increases linearly with depth were already known to earthquake seismologists and to meteorologists before the advent of seismic exploration for oil. The convenient property that the trajectories and also the wave fronts in such a medium are circles is, for instance, implied in formula (117) of V. Conrad's article in the *Encyklopaedie der Mathematischen Wissenschaften* (1925). The curvature of a ray is given there as $1/\rho=(dv/dr)\ (\sin i)/v$ where ρ is the radius of curvature, v the velocity at a distance r from the center of a spherical earth, and i the angle between the radius and the trajectory at the point where the curvature is being measured. This formula is readily applicable to plane parallel layers. For this particular case the circular path is derived by O. Meisser[1] in a treatise on sound transmission in the atmosphere. Meisser refers to a not easily accessible publication of Wiechert[2] as the first explicit application of the curvature formula to plane parallel layers.

With the development of seismic exploration, the practical importance of this simplest possible increase of speed with depth became apparent, and the subject was well covered in this journal and other publications by Ewing and Leet,[3] Slotnick,[4,5] Peterson,[6] and Hafner[7] as well as numerous other authors. The existence of many areas in which such an increase of speed closely approximates the actual conditions has led to a wide use of this velocity function, and even in areas in which another velocity function would provide somewhat greater ac-

* Manuscript received by the Editor November 1, 1947.

† Shell Oil Co., Inc., Exploration and Production Research Laboratory, Houston, Texas.

[1] O. Meisser, *Handbuch der Experimentalphysik*, Bd. 25, Teil 3, 1930, p. 219.

[2] E. Wiechert, *Göttinger Nachrichten*, Heft 1, (1925), pp. 49–65.

[3] Maurice Ewing and L. Don Leet, "Seismic Propagation Paths," Trans. A.I.M.E., *Geophysical Prospecting* (1932), pp. 245–262.

[4] M. M. Slotnick, "On Seismic Computations, with Applications, I," *Geophysics*, I (1936), 9–22.

[5] M. M. Slotnick, "On Seismic Computations, with Applications, II," *Geophysics*, I (1936), 299–305.

[6] R. A. Peterson, "A Transformed Wave-Front Chart," *Geophysics*, VI (1941), 74–80.

[7] W. Hafner, "The Seismic Velocity Distribution in the Tertiary Basins of California," *Seis. Soc. of Am. Bull.*, *30*, (October, 1940).

curacy, a linear increase of velocity with depth is sometimes assumed for the convenience of working with circular trajectories and wave fronts. The application of this velocity function in the migration of reflections can be made still more convenient by the use of formulas expressing the depth of the center of the wave-front circle and its radius of curvature as simple algebraic functions of known geometric quantities, i.e., the unmigrated depth and the constants of the velocity distribution, rather than as hyperbolic functions of the travel time. By virtue of their simplicity, these formulas have proved their value in practical use (by the Shell Oil Company and some contracting companies working under its direction) since 1939. As they do not seem to have found their way into the literature, they are contributed herewith.

Let the velocity function be

$$V_z = V_0 + kz = V_0(1 + z/L) \tag{1}$$

where V_z is the velocity at a depth z, V_0 the velocity at the surface, k the constant of linear increase, and $L = V_0/k$. That the trajectories are circles was proved by Meisser and also Ewing and Leet, who applied the calculus of variations to the expression for the travel time between two points in a medium with this type of velocity increase. The brachystochrone, or path of least time, then is shown to be a circle.

The circular path also follows as a special case from the general formula for the radius of curvature of the ray, for horizontal speed layers, which is given by

$$\rho = ds/di = dz/(\cos i\, di) = dz/d(\sin i). \tag{2}$$

By Snell's law

$$\sin i/V = \text{const.} = 1/V_m,$$

or

$$\sin i = V/V_m,$$

where V_m is the maximum velocity reached at the deepest point of the trajectory. Hence,

$$\rho = dz/d(V/V_m) = V_m \cdot dz/dV. \tag{3}$$

From equation (1), however,

$$dz/dV = 1/k;$$

hence

$$\rho = V_m/k \tag{4}$$

and is therefore constant. Consequently for the case of the linear increase of speed with depth the trajectories are circular.

It has been shown in the literature that the centers of all trajectory circles lie on the same horizontal line at distance $L = V_0/k$ above the surface. That

this is so is easily seen by considering the vertical radius ME (Fig. 1) of one of the circles.

$$ME = \rho = V_m/k = (V_0 + kz)/k = V_0/k + z = L + z. \tag{5}$$

Thus all trajectory circles have their centers on a horizontal line at a distance L above the surface, and since they all pass through the shotpoint O, they pass for reasons of symmetry also through a point O' at a distance $2L$ vertically above it. According to a theorem of analytic geometry, the orthogonal trajectories of

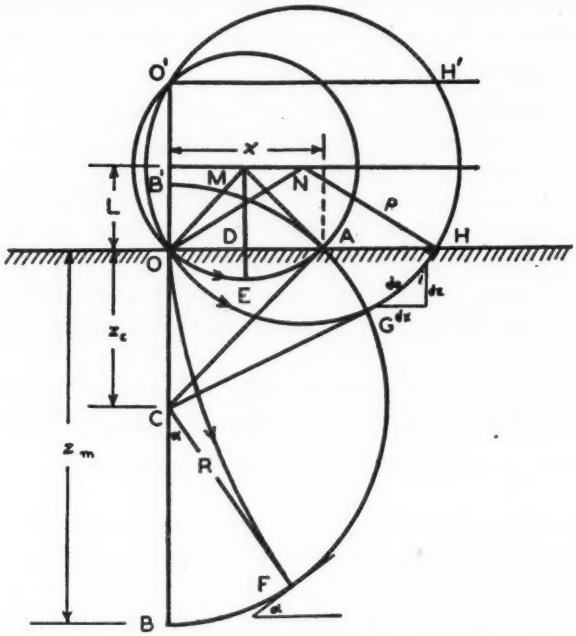

FIG. 1. Trajectories and wave-front circle for a linear increase of velocity with depth.

such a pencil or family of circles form a second pencil or family of circles, i.e., in this case the wave fronts. The proof can be obtained analytically from the differential equation of orthogonal trajectories, or can be seen from Figure 1 by drawing from any point C vertically below O the tangents to all the trajectory circles, two of which, with centers at M and at N, are shown. These tangents are all of equal length, namely $(CO \times CO')^{1/2}$, $CO \times CO'$ being the power of the point C with respect to every one of the trajectory circles.* Hence a circle with

* In Figure 2, CPQ is a line through C intersecting the circle but otherwise arbitrary. The equality of the product $CP \times CQ$ (also called the power of the point with respect to the circle) to the square of the length of the tangents from the point to the circle is a well-known theorem of geometry, which is proved from the similarity of triangles CRP and CQR. These have a common angle at C while $\angle CRP = \angle CQR = (1/2)$ arc PR. From the similarity it follows that $CP:CR = CR:CQ$ or $CP \times CQ = CR^2$.

its center at any point C vertically below O and having a radius $R=(CO\times CO')^{1/2}$ is an orthogonal trajectory of the pencil of seismic rays through O, and is therefore a wave front.

The depth z_c to the center of a wave-front circle is obtainable by solving simultaneously the two equations:

$$R^2 = CO \times CO' = z_c(z_c + 2L), \tag{6}$$

and

$$R^2 = (z_m - z_c)^2, \tag{7}$$

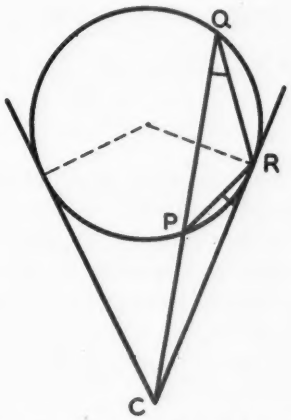

FIG. 2. Proof of geometrical theorem.

where z_m is the maximum depth reached by the wave-front circle and is also the depth which in vertical-incidence reflection work would be obtained as the unmigrated depth of reflections. From equations (6) and (7)

$$z_c = z_m^2/(2L + 2z_m). \tag{8}$$

From equation (1)

$$z_m = (V_z - V_o)/k \quad \text{and} \quad L = V_o/k.$$

Partial substitutions of these into equation (8) gives

$$z_c = z_m(V_z - V_0)/2V_z. \tag{9}$$

Analogously the radius R of the wave-front circle is given by:

$$\begin{aligned} R &= z_m - z_c = z_m - z_m^2/(2L + 2z_m) = z_m(2L + z_m)/(2L + 2z_m) \\ &= z_m(V_z + V_0)/2V_z. \end{aligned} \tag{10}$$

If we start from the widely used formulas

$$R = L \sinh kt \quad \text{and} \quad z_c = L(\cosh[kt] - 1),$$

where t is the one-way travel time, instead of from first principles as has been done above, then the formulas (8), (9), and (10) can be derived by observing that:

$$R = L \sinh [kt] = L \sinh \ln (V_z/V_0) = \frac{L}{2} \left\{ e^{\ln (V_z/V_0)} - e^{-\ln (V_z/V_0)} \right\}$$

$$= \frac{L}{2} \left\{ \frac{V_z}{V_0} - \frac{V_0}{V_z} \right\} = \frac{L}{2} \left\{ \frac{L + z_m}{L} - \frac{L}{L + z_m} \right\} = \frac{z_m^2 + 2Lz_m}{2L + 2z_m}.$$

The following additional properties are of interest. In Figure 1, $AGFB$ is the position of the wave front at the time of arrival at A of the initial disturbance. From the similar triangles ADM and COA it follows that

$$MD:DA = AO:OC, \quad \text{or} \quad L:x/2 = x:z_c$$

and

$$z_c = x^2/2L. \tag{11}$$

This equation gives the instantaneous depth of the center of the wave-front circle in terms of the horizontal distance at which the wave front intersects the surface. This, as well as a similar expression which can be derived for R, is of more interest in refraction than in reflection work.

A property which so far has only theoretical significance follows from the equation $R^2 = CO \times CO'$, which can be written alternatively $R:CO = CO':R$. Since $OB' = R - CO$, $O'B' = CO' - R$, $OB = R + CO = z_m$, and $O'B = CO' + R = z_m + 2L$, there follows:

$$OB':O'B' = OB:O'B = z_m:(z_m + 2L), \tag{12}$$

so that the points O and O' divide every diameter BB' harmonically, and the line $O'H'$ is the polar of the shotpoint O with respect to all the wave-front circles. This property can be used to explain the analogy of this system of orthogonal circles with similar systems of circles in the field of electrostatics.

Formula (8) has found practical application in the migration of dips. In Figure 1, z_m is known from the original computation of the depth to the unmigrated dip α, and z_c may be obtained from z_m by means of a graph of the function $z_c = z_m^2/(2L + 2z_m)$. A small graph, on a scale about one-fifth of the scale of the profile under consideration, affords sufficient accuracy in routine work. The graph is used in conjunction with a transparent print of a system of concentric circles and radial lines giving α. Providing the magnitude of the dip, α, is accurately determined and the proper corrections have been applied, this procedure enables the computer to migrate dips speedily and with an accuracy limited practically only by the degree to which the assumed linear velocity departs from the actual velocity distribution. The main application of these formulas has been in areas of small or moderate dips, where migration is not always necessary and where, therefore, wave-front charts or mechanical devices equivalent to wave-front charts are not in constant use.

MAGNETIC PROPERTIES OF "GRANITE" WASH AND UNWEATHERED "GRANITE"*

GARVIN L. TAYLOR† AND DUANE H. RENO†

ABSTRACT

Routine measurements of the magnetic properties of various geological formations show that "granite" wash, although having an appearance in well samples very similar to that of unweathered "granite," has very different magnetic properties. Magnetic logs of wells located in Southwestern Oklahoma, Texas Panhandle and Eastern New Mexico show a large increase in the magnetic susceptibility when unweathered "granite" is encountered. Samples of "granite" and "granite" wash collected from the Wichita Mountains in Oklahoma show a marked decrease in magnetic susceptibility during the formation of "granite" wash from unweathered "granite." It is concluded that magnetic logs made by testing well samples will be of assistance in differentiating "granite" wash from the underlying unweathered "granite." Tests of samples of unweathered "granite" upon exposure to weather show a measurable to marked decay of susceptibility and remanent magnetism in the relatively short time of a few years.

INTRODUCTION

During the course of a routine study of the magnetic properties of various geological formations encountered during drilling operations, it was noted that "granite wash," or arkose, had a much lower magnetic susceptibility and remanent magnetism than did the "granite" in place. This indicated a new approach to the old and sometimes difficult problem of distinguishing between granitic detritus which has been eroded, carried a short distance and redeposited, and the "granite" in place. It is obvious that the difference may be slight between a number of "granite" cobbles or boulders broken into small fragments by the drill, and a solid "granite" broken into similar fragments. The usual microscopic examination often cannot differentiate the two by mineral changes, weathering, or rounded surfaces, when drill cuttings only are available. To check the validity of the magnetic data and to gain more knowledge to aid in its interpretation, a series of measurements on "granite" wash and unweathered "granite" have been made. These rock samples and well cuttings were measured for the amount of magnetic susceptibility and the remanent magnetism, two of the common magnetic properties. Other magnetic properties or characteristics of a rock are infrequently measured. Susceptibility is defined by Nettleton[1] as follows: "When a magnetizable body is placed in a magnetic field it takes on a certain degree of magnetization. The measure of the ease of magnetization is the susceptibility." Heiland[2] separates the various phases of rock magnetization as follows: "It is composed of two phases; one remains the same regardless of orientation of a

* Presented at the Tulsa Regional Meeting of the Society of Exploration Geophysicists, May 22, 1947. Manuscript received by the Editor August 14, 1947.

† Stanolind Oil and Gas Company, Tulsa, Oklahoma.

[1] L. L. Nettleton, *Geophysical Prospecting for Oil* (McGraw-Hill Book Co., 1940), p. 160.

[2] C. A. Heiland, *Geophysical Exploration* (Prentice-Hall, 1940), p. 297.

specimen, while the other reverses its sign when the specimen is reversed. The former is called induced, the latter the remanent magnetization."

Two rock specimens having the same susceptibility may show extreme difference in the amount of remanent magnetization. Remanent magnetization is primarily the result of the past physical history of the rock. Of course, it is necessary for the rock to have some magnetic susceptibility before it can display any appreciable amount of remanent magnetization.

The meaning of the term "granite" as used in this report is different than that commonly used in drilling reports on oil wells. Also it differs considerably from the definition given in most textbooks of petrology. "Granite" as often used in drilling reports means any igneous or metamorphic rock occurring below the sedimentary section common in that particular area. "Granite," as used for simplicity in this report, includes granites, syenites, diorites, granodiorites, monzonites and their fine-grained, or aphanitic, equivalents as defined by Holmes.[3] "Granite" wash is the material eroded from outcrops of these types of igneous rocks and redeposited, forming a rock having approximately the same major mineral constituents as the original rock. The usage of these terms in this report will agree closely with the usual usage in southwestern Oklahoma and the Panhandle of Texas where formations of "granite" wash are common and the "basement" rock, most common, is a crystalline igneous rock of the "granite" type. The "granite" wash of this area, if not mixed with shales, sands, or limestones, has practically the same mineral composition and appearance as a crushed sample of an unweathered fragment of the original "granite." A typical sample of well cuttings from beds of solid wash will be composed of fragments of quartz, and of potash and plagioclase feldspars, ferro-magnesian minerals, and small amounts of the various accessory minerals. These minerals are usually in almost the same proportion as they might be expected to occur in a crushed sample of the original rock. In some beds the fragments may show distinctive weathering characteristics. In others, it is difficult to be sure that the weathering characteristics such as rounding of grains, chemical and optical alterations of the feldspars and ferromagnesian minerals, and other physical and chemical changes are not in part primary; or that the fragments showing definite wash characteristics are not from a higher formation and are falling from the wall of the hole during the drilling operations. Wash from basic igneous rocks such as gabbros and basalts is very scarce. This "basic wash" has entirely different characteristics than the "granite" wash. Detritus from basic igneous rocks is usually logged as green "clay-like" or silty shales, and such materials have been noted in wells and on the surface in the Wichita Mountains area, as well as in the Panhandle area of Texas. These thin greenish shale beds are usually rare, if present at all, but are easily separated from unweathered "granite" by casual microscopic examination. The magnetic susceptibility of the "basic shales" is usually high.

Two types of data were obtained to check the assumption indicated by the

[3] Arthur Holmes, *The Nomenclature of Petrology* (London, 1920), pp. 268–77.

inferred data that the induced and remanent magnetization of "granite" wash are probably much lower than those of the original "granite." First, cores of unweathered "granite" were crushed and exposed to the weather and periodically tested for changes in magnetic properties. Second, samples of unweathered "granite" and "granite" wash were collected from surface exposures so that the relation of the "granite" wash to the unweathered "granite" could be established. These controlled surface samples were then tested for their magnetic properties.

METHOD OF SUSCEPTIBILITY DETERMINATION

The instrument used by us for measuring the magnetic susceptibility of a rock or drill sample representative of a geologic formation is a two-coil inductance-comparison bridge. It is somewhat similar to instruments described by Wm. M. Barret[4] and H. Wayne Holman and H. A. Durbin.[5]

This instrument was designed to be used on small samples that would be readily available from almost all wells drilled (without requesting extraordinarily large samples). Ability to measure the susceptibility of a sample 2 cc. in volume, having a susceptibility of 5×10^{-6} c.g.s. units, was a requirement placed on the design of the instrument. Also the determination was to be made so as to represent the true susceptibility of the formation under the influence of the small static field of the earth. The sensitivity of the instrument is $\pm 2\times10^{-6}$ c.g.s. units, which is considered quite adequate for geophysical purposes. A Permian "red bed" sample and a granite sample were tested at field strengths of 0.5, 1.0, 1.5, 2.0 and 4.0 oersteds. Over this range no significant change in the determination of susceptibility was observed. A field strength of 2 oersteds which is about four times the total intensity of the earth's field, was selected as a suitable field strength for routine determination.

The instrument was calibrated by using a set of chemically pure compounds whose magnetic susceptibilities are listed in the *Handbook of Chemistry and Physics*.[6] Since the susceptibilities of the standards have been derived from a number of sources, and their magnetic susceptibilities have not been determined at a standard field strength, the calibration and the observed susceptibilities made by the present instrument may be in error by as much as 25 per cent in absolute value. This factor, however, does not affect the relative magnetic susceptibilities of the samples determined by this instrument.

The procedure for making magnetic-susceptibility determinations is quite simple and has been reduced to a standard technique. As most of the routine work is with well cuttings, the technique for determination on this type of material will be described. Since nearly all of the routine determinations made are

[4] Wm. M. Barret, "A Method for Determining Magnetic Susceptibility of Core Samples," *AIME, Geophysical Prospecting* (1932), p. 216.

[5] H. Wayne Holman, and H. A. Durbin, "A Study of the Susceptibility of Sediments," *Trans. Am. Geo. Union, Part IV* (1944), p. 543.

[6] *Handbook of Chemistry and Physics* (Chemical Rubber Publishing Co., 1941), pp. 1873–1882.

associated with the formations or divisions of a geological section, one laboratory sample may represent more than a hundred feet of rock. The laboratory sample is representative of part or all of one formation. The well samples if "dirty," are washed and dried before any other operation is started. No significant change in the determination of susceptibility was observed when the effect of washing and drying of a sample at temperatures commonly used in a geological laboratory or in the field was tested. A small portion representative of the formation being drilled is removed from each well sample, the most common well sample being a "10-foot sample." These small fractions are then grouped as one laboratory sample. The size of the laboratory sample will depend on the geological section it represents and the size of available well samples. The combined laboratory sample is usually from 4 to 6 grams in weight. It is desirable to have a larger sample since then it may be split into two or more equal parts and the separate determinations used as a check on the presence of iron fragments. The iron fragments, from the bit, drill, pipe and casing, common in well samples, are removed from each laboratory sample by a small magnet. No significant change in the determination of susceptibility of a rock was observed when the effect of using a small magnet for iron removal was tested. All material removed from a sample is examined under a microscope to make sure it is iron and not a magnetic mineral that should be present in the rock. After the removal of most of the iron fragments, it is unlikely that the remaining iron will be distributed equally between the equal fractions of the sample. Therefore, because the iron fragments have a high susceptibility, a disagreement in the susceptibility determinations of each part will indicate the presence of some remaining iron fragments. This method and a comprehensive examination with a microscope are sufficient to effect a complete removal of foreign iron from the samples.

The density of the rock to be tested is first determined and then 4 to 6 grams of the laboratory sample are placed in a glass vial approximately $\frac{1}{2}$ inch in diamter and $2\frac{1}{2}$ inches long. This glass vial is fitted with a long cork that reduces the effective length of sample to a standard value of $1\frac{5}{8}$ inches. This standard length places the sample in the central portion of the coil where the field is uniform. The weight and volume of the vial are determined to ± 0.001 gram. The instrument is balanced in the absence of the sample by adjusting the amount of resistance in appropriate arms of the bridge, then the vial with its contained sample is inserted into the coil and the instrument is rebalanced. Several readings are made on each determination so that an average resistance change is determined.

The susceptibility of the sample is:

$$K = (D/D_1)SR$$

in which D is the rock density, D_1 is the sample density (volume of the glass vial divided by the mass of the sample packed into it), S is the scale factor of the instrument, and R is the resistance change.

Because of slight errors in "sample density," a single determination of

susceptibility is probably accurate to $\pm 5 \times 10^{-6}$ c.g.s. units. Repeated determinations will increase the accuracy towards the reading error of the instrument which is $\pm 2 \times 10^{-6}$ c.g.s. units. After a sample is "clean" and ready for determination, the actual time required to make the susceptibility determination is very short.

MAGNETIC TESTS OF WICHITA MOUNTAIN OUTCROP SAMPLES

Samples of unweathered "granite," weathered "granite" and wash derived from the same "granite" were collected from several outcrops in the Wichita Mountains in Southwestern Oklahoma. The igneous rocks in this area are deeply weathered on the surface so that it was necessary to restrict the collecting of material to road cuts or quarries. In some instances, unweathered "granite" was not obtainable and only weathered "granites" were collected. This type of rock can be disintegrated easily by light hammering and is weathered until a part or all of the ferro-magnesian minerals are altered. This type of material is referred to in this report as "deeply weathered granite." It was believed at that time that this "granite," deeply weathered in place, would have magnetic properties somewhat similar to "granite" wash. Laboratory measurements proved that the susceptibility and remanent magnetization of the "deeply weathered granite" were as low or lower than those of the "granite" wash where both were obtained. The "granite" wash samples were collected from draws, quarry drains and small streams draining only areas from which the weathered and unweathered samples were obtained. In this way positive control, insofar as is possible to obtain this in the field, was maintained as to the original source of the wash. This "granite" wash would be considered as very young in geological age. The fresh samples were collected in road cuts and quarries which exposed rocks well below the average surface. Some of the samples of supposedly unweathered rock not collected from quarries and road cuts when examined microscopically in the laboratory were found to be weathered so badly that they were not suitable for use in the magnetic tests. In a few quarries slightly weathered "granite" specimens were collected. These specimens were hard, competent rocks, but could be distinguished visually from the unweathered rocks by a color change on the quarry face. The color change paralleled the original ground surface. In the case of the quartz monzonite from the Cold Springs area, the slightly weathered rock was hard and competent enough that it has been quarried for commercial use. Samples of this type are referred to as "slightly weathered granite" on Figure 1.

Lugert-type Granite.—Samples of the Lugert-type granite were collected from four localities. They are as follows: Section 23, Township 3 North, Range 14 West; Section 5, Township 4 North, Range 20 West; Section 32, Township 5 North, Range 18 west; Section 25, Township 3 North, Range 17 West.

The Lugert-type granite has been described by C. H. Taylor.[7] This rock is a

[7] C. H. Taylor, "Granites of Oklahoma," *Oklahoma Geological Survey Bulletin No. 20* (July, 1915), pp. 62–63.

finely crystalline, equigranular, red granite composed of feldspar and quartz with subordinate amounts of augite, hornblende, magnetite, biotite and microscopic hematite, zircon and titanite. The feldspar is chiefly orthoclase and microperthite—an intergrowth of orthoclase and albite feldspars. The percentages of the minerals are feldspars, 60–65 per cent; quartz, 30–35 per cent; ferro-magnesian minerals, 5 per cent or less.

Data "A" on Figure 1 show the average magnetic susceptibility of the various samples of Lugert granite. The average magnetic susceptibility of the unweathered Lugert granite from three localities is 331×10^{-6} c.g.s. units, and the "deeply weathered" Lugert granite has an average magnetic susceptibility of 16×10^{-6} c.g.s. units. The Lugert granite wash was collected from a ravine draining a small

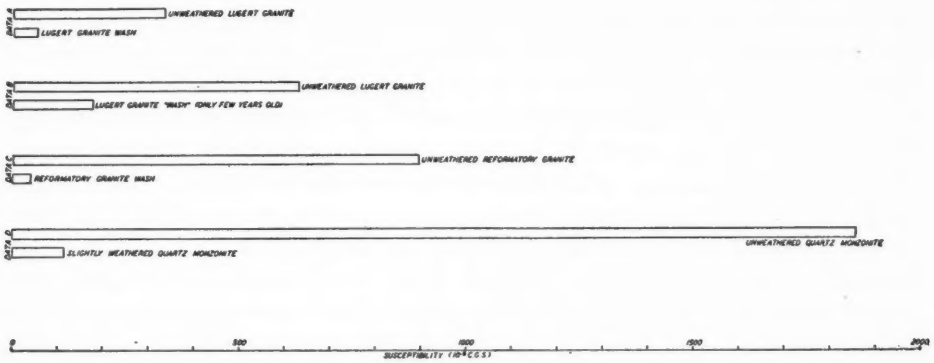

FIG. 1. Average susceptibility of various samples of unweathered and wash samples of two types of Wichita Mountains "granite," and of unweathered and slightly weathered quartz monzonite from the same locality.

area of a few hundred square feet near the top of a hill of Lugert granite in Section 32, Township 5 North, Range 18 West. It is believed that only Lugert granite could be the source of the wash material collected. The magnetic susceptibility of this wash is 50×10^{-6} c.g.s. units. It is apparent that there is a large decrease in the magnetic susceptibility from the unweathered granite to the granite wash and "deeply weathered granite."

Data listed "B" on Figure 1 are also for Lugert granite. These samples were collected in an abandoned quarry north of Mountain Park in Section 23, Township 3 North, Range 17 West. The unweathered granite was obtained from several places on the quarry face and has an average susceptibility of 623×10^{-6} c.g.s. units. The "wash" was collected from a very small drain on the quarry floor and appeared to consist of small crushed fragments of granite produced by quarrying operations. The average magnetic susceptibility of this "wash" is 174×10^{-6} c.g.s. units. The age of the granite wash is probably close to thirty years, since this quarry has not been worked to any great extent, if at all, during that length of time. This decrease in magnetic susceptibility in a very short time geologically

is considered a strong indication that the magnetic susceptibility of small granite fragments changes faster than the mineralogical alterations usually relied on to distinguish granite wash from granite in place.

Reformatory-type Granite.—Data "C" shown on Figure 1 are for the Reformatory Granite of the Wichita Mountains. This granite is described by C. H. Taylor.[8] The Reformatory granite is a red, even-granular, medium to coarsely crystalline granite composed of orthoclase, microperthite, quartz and hornblende with the accessory minerals hematite, zircon, titanite, fluorite and magnetite. Mineral percentages are 60 percent feldspar, 33 percent quartz, 5.5 percent hornblende and 1.5 percent accessories.

Samples were collected from three localities, which are as follows: Section 21, Township 5 North, Range 20 West; Section 9, Township 6 North, Range 21 West; Section 22, Township 6 North, Range 21 West.

As shown on Figure 1, the average magnetic susceptibility of the unweathered granite is 890×10^{-6} c.g.s. units, and in the granite wash the magnetic susceptibility had decreased to 39×10^{-6} c.g.s. units. The granite wash samples were collected from the beds of small streams that drained areas underlain by Reformatory granite. Samples of "deeply weathered" Reformatory granite were also very low in magnetic susceptibility. The decrease in magnetic susceptibility of the Reformatory granite upon weathering agrees well with the decrease shown by the Lugert granite.

Quartz Monzonite.—Data "D" on Figure 1 are for the quartz monzonite exposed near the town of Cold Springs in Township 4 North, Range 17 West. The quartz monzonite as described by C. H. Taylor[9] consists of orthoclase, andesine, quartz, hornblende, biotite and accessories of magnetite, apatite, pyrite and titanite. Mineral percentages are feldspars, 62 percent; quartz 19 percent; hornblende, 12 percent; biotite, 6 percent; accessories, 1 percent. The rock is mottled gray and white, with a medium crystalline equigranular texture.

The slightly weathered sample, as previously described, was distinguishable from the underlying unweathered rock by a slight color change, but was a well consolidated rock since both have been quarried for commercial use. The color change was parallel to the surface exposure indicating that it was very probably the result of weathering. Also, microscopic examination of the slightly weathered rocks indicated that the difference was due to weathering and not to original mineralogical variations in the monzonite. The unweathered sample has an average magnetic susceptibility of $1{,}853 \times 10^{-6}$ c.g.s. units, whereas the slightly weathered sample shows a large decrease and has a susceptibility of only 112×10^{-6} c.g.s. units.

It is believed that sufficient care was taken in collecting the samples of unweathered granite, weathered granite, and granite wash to virtually eliminate the possibility that the magnetic susceptibility variations shown on Figure 1 were

[8] C. H. Taylor, *op. cit.*, pp. 44–45.

[9] C. H. Taylor, *op. cit.*, pp. 72–74.

caused by original variations in the granite and not by weathering. As was previously stated, the samples were collected at several different localities so as to obtain averages for "wash" and unweathered "granite." But at each locality samples were collected in close proximity to better eliminate the original or primary magnetic variations in the "granite" masses. Because the data show that in all samples the magnetic susceptibility decreases on weathering, it is very unlikely that any primary local variation in the igneous masses is reflected in the data shown on Figure 1 and wrongly attributed to weathering.

SHORT-PERIOD WEATHERING TESTS ON "GRANITE"

In order to determine if any observable change in magnetic susceptibility would occur in a relatively short period of time, samples of "granite cores" were exposed to weathering. The magnetic susceptibility of crushed samples from two granite cores was measured at various times over a period extending from December, 1943 to January, 1947. These granites are designated as "A" and "B." Granite "A" is from a well drilled in Hale County, Texas. Granite "B" is from a shallow core hole on the south flank of the Wichita Mountains. These "granite" cores appeared to be unweathered. Thin sections were prepared from the cores and upon examination showed no mineralogical alterations present that could be considered as produced by weathering.

Granite "A" is a red, medium crystalline rock composed of orthoclase feldspar, a plagioclase feldspar, quartz, biotite, hornblende and accessories of apatite, zircon and magnetite. The feldspars have been partially altered hydrothermally to sericite, and the biotite has been altered in part to chlorite and magnetite. The hornblende has been changed in part to serpentine with titanite, calcite and magnetite as by-products. The mineral percentages are plagioclase feldspar, 35 percent; quartz, 25 percent; orthoclase, 30 percent; biotite, 5 percent; hornblende, 4 percent; and accessories 1 percent or less.

Granite "B" is a dark-red, finely crystalline, porphyritic rock. The mineral constituents are phenocrysts of andesine and ferro-magnesian minerals in a fine-grained ground mass of plagioclase feldspar, orthoclase, quartz, and abundant myrmekite—intergrowth of quartz and orthoclase. Accessory minerals are magnetite, hematite and zircon. Secondary minerals are chlorite, calcite, serpentine and epidote.

A fragment of each core approximately 3 inches square was crushed to several grade sizes to measure the effect of particle size on the amount of decrease of the magnetic susceptibility. The crushed rock was divided into four sizes by separation on U. S. Standard-size sieves of 10-mesh, 20-mesh, 40-mesh and 80-mesh sizes. These sieves are made of fine brass wire, and the number, or mesh, indicates the number of wires per inch. The openings between the wires are: for the 10-mesh size, 1.98 mm.; for the 20-mesh size, 0.833 mm.; for the 40-mesh size, 0.417 mm.; and for the 80-mesh size, 0.175 mm. For example, the sample which passed the 10-mesh but was retained on the 20-mesh screens would therefore be composed

of fragments varying from 1.98 mm. to 0.833 mm. These samples were placed in containers which were put in a wooden tray and set on top of a house. The samples were first put in glass containers, but these were shattered by freezing of water in them during cold weather. Plastic containers were then tried, but with similar results. Finally aluminum cans about 5 inches deep by 2 inches in diameter proved satisfactory. The samples were exposed to the elements and at times were covered with water and at times dry, depending on the amount of natural moisture and evaporation. The wooden tray was made of slats in order to expose the containers to the weather as much as possible. The tray and samples were placed on the roof of a house instead of on the laboratory roof in order to eliminate any possible effect of the strong electrical fields common near a laboratory. Periodically, the samples were taken from the roof, foreign materials such as leaves, insects, and dust removed, and the magnetic properties were measured in the laboratory.

The samples were separated according to grade size because it was thought that the change in susceptibility caused by weathering might be partly controlled by the size of granite fragments. Unfortunately, no conclusive proof of this possibility was obtained because of the mineralogical auto-sorting in the grade-size sample. The four samples of each unweathered granite were of different-size fragments, but also the magnetic susceptibility of each sample was slightly different. This suggested the possibilities that any variation in the rate of susceptibility change might be controlled by the size of the fragments or by the original susceptibility. The samples with the higher original susceptibility might be more unstable and change faster than the samples of lower original susceptibility. The present data as shown on Figure 2 indicate that both granites "A" and "B" decreased a measurable amount in the short time of slightly over three years. Granite "A" has a slightly higher susceptibility than granite "B" and shows a greater decrease than granite "B"; this may indicate that a "granite" of higher susceptibility will decrease in susceptibility faster than a "granite" of lower susceptibility. The 40- to 80-mesh samples of granite "B" decreased slightly faster than the greater than 10-mesh sample, but had a higher original susceptibility. The 40- to 80-mesh sample of granite "A" decreased faster than the large grades of the same granite, and had a lower original susceptibility. This may be an indication that the size of the fragments also control the rate of change of susceptibility. Although there is not enough control for conclusive proof, there is a definite indication that a granite of high susceptibility will decrease in susceptibility faster than a sample of low susceptibility; also, the granite crushed into a finer "granite wash," will show a faster decrease in susceptibility than a "coarser granite wash." As previously stated, the data on Figure 2 show that an unweathered "granite," crushed until it resembles a wash, decreases in magnetic susceptibility upon exposure to weather. This decrease is much slower than the decrease in remanent magnetism, as will be shown later.

Remanent Magnetism of Granite Cubes.—In order to test the amount and the

rate of change of the remanent magnetism of granite upon exposure to weather, small cubes were cut from a core of unweathered granite. These cubes were exposed under the same conditions as used and described on the crushed material in testing for change in the magnetic susceptibility. The cubes were cut from the same granite core which was designated as granite "A" in the magnetic susceptibility tests.

Six cubes were cut from the core of granite "A." These cubes were approximately $\frac{3}{8}$ inch on a side, and were all nearly the same size. They were treated in the same manner as the crushed granite samples: that is, they were placed in a

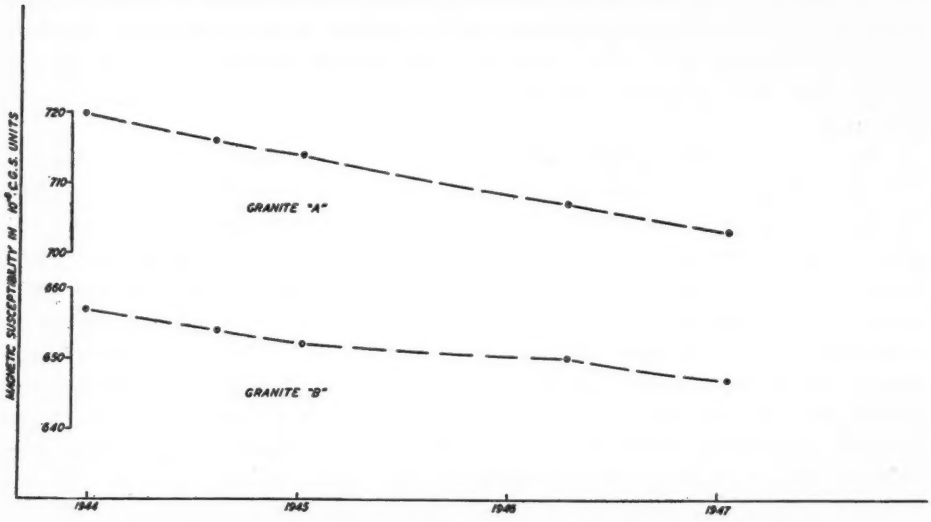

FIG. 2. Decay of susceptibility of crushed fresh "granite" cores during three year exposure to weather.

container on a roof and exposed to the weather. The cubes were first put on the roof in December, 1943, and were taken down and tested periodically for changes in the remanent magnetism.* The results are shown on Figure 3, in which a percentage decrease of the remanent magnetism is plotted against the time. The curve shows that the greatest change in the remanent magnetism takes place in a relatively short time after exposure to weather. The curve then flattens considerably, indicating that after the large initial decrease the remanent magnetism of this granite is more stable and decreases at a slower rate. A corollary to this fact, not indicated on Figure 3, is that a rock cube with a low original remanent magnetism had a slower rate of decrease than a rock cube with a high original

* The apparatus used for determination of the remanent magnetism consisted of means for rotating the sample at constant angular velocity within a pair of pick-up coils, and suitable amplifying, phase-shift, and detecting means. It is similar in principle to that described by E. A. Johnson, *Terrestrial Magnetism and Atmospheric Electricity* (1938), pp. 393–399.

remanent magnetism. This is illustrated by two of the cubes, both the same size and from nearly the same part of the original core. One of these cubes had an original remanent magnetism of 325×10^{-6} c.g.s. units. At the end of the test period, it had decreased only 23 percent. The other cube had an original remanent magnetism of 9800×10^{-6} c.g.s. units. The decrease of the remanent magnetism of this cube was very rapid, and at the end of the first year it had lost 40 percent of its original magnetism. Since the cubes were of the same size and from almost adjacent positions in the core, it is believed that the major cause of the large drop in remanent magnetism of the second cube is the unstable condition of a

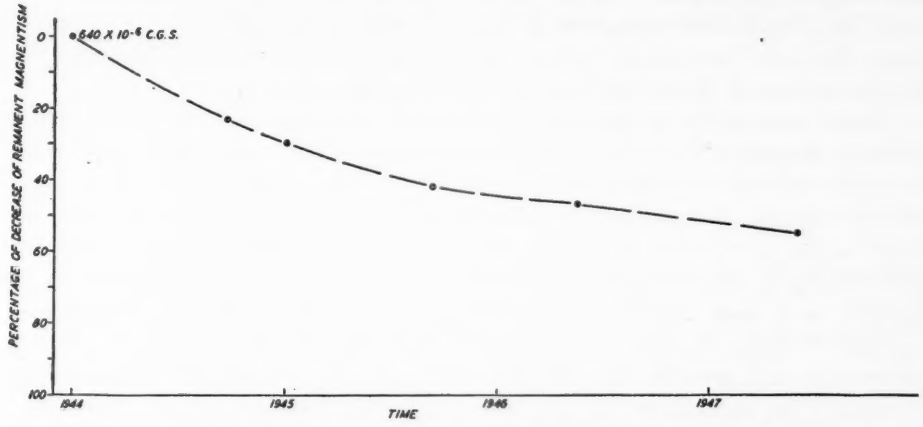

FIG. 3. Average percentage decrease of remanent magnetism of six fresh granite cubes after three-year exposure to weather.

rock with a high original remanent magnetism. It is believed that, in all probability, larger fragments of rock will have a slower rate of decrease of remanent magnetism than smaller fragments. This, it is believed, would be caused by the fact that the amount of weathering of the large rock fragments would be less compared to the volume of the fragment than in the smaller fragments. This fact would be more obvious in the rock fragments produced by natural means, because in some cases, the weathering processes have penetrated deep into the rock before its erosion. Also, after the rock fragments had been removed from their original location, the weathering and alterations of the minerals would continue and even be intensified under some environments. The data from the one cube having an extremely high original remanent magnetism are not included in the average-decay curve as shown on Figure 3. The data from six cubes that had an original average remanent magnetism of 640×10^{-6} c.g.s. units were used to make the curve shown on Figure 3. Since the cube of high remanent value was not included it is probable that the actual remanent magnetism of the "granite" would be approximately 2000×10^{-6} c.g.s. units.

It is apparent from the decay of the remanent magnetism as shown on Figure

3 that "granite" fragments produced by nature to form a "granite" wash should be much lower in remanent magnetism than the parent rock.

MAGNETIC LOGS OF WELLS WHICH ENCOUNTERED "GRANITE WASH" AND "GRANITE"

The magnetic susceptibility and remanent magnetism of the well samples has been used in several wells to determine whether the well was drilled into unweathered "granite" or into wash derived from unweathered "granite." Some of these wells have been the subject of controversy and the magnetic measurements determined or aided in determining an answer to the problem. The magnetic logs and sample logs of a few wells are shown to illustrate the differences in the magnetic log of wash and unweathered "granite" and to illustrate some of the problems. The wells used for illustration were drilled in Southwestern Oklahoma, the Panhandle area of Texas and Northeastern New Mexico.

Figure 4 shows the sample logs and magnetic logs of two wells drilled in Southwestern Oklahoma. Well No. 1 is located in Comanche County. This well drilled 1,420 feet of brown and gray shales interbedded with "granite wash." This upper section contains fine-grained "wash," which should more properly be called arkosic sands, in addition to beds containing reworked limestone and dolomite that should be called conglomerates. From 1,420 to 1,640 feet the "granite" wash samples were made up of large "fresh" appearing fragments of a red, fine-grained "granite." The rock fragments contained dark reddish-colored feldspar, quartz, myrmekite intergrowths with chlorite as an accessory mineral. The unweathered "granite" was encountered at 1,640 feet and penetrated for 179 feet. The "granite" is dark reddish in color and is composed of myrmekitic intergrowths of quartz and feldspar with chlorite as an accessory mineral. The cores and thin-sections indicated that chlorite could not be considered a mineral formed by weathering as related to the present weathered top of the "granite" encountered by drilling, but the chlorite is probably the result of hydrothermal alteration. The magnetic-susceptibility log shows the rock encountered down to a depth of 1,420 feet has a susceptibility of approximately 20×10^{-6} c.g.s. units. The "fresh" appearing solid wash from 1,420 to 1,640 feet has a very slightly higher susceptibility of 28×10^{-6} c.g.s. units. The unweathered "granite" has a much greater susceptibility of 175×10^{-6} c.g.s. units. The top of the unweathered "granite" was determined first by the use of the susceptibility log and later petrographic study of thin sections of cores indicated it was correct. Well log No. 2 on Figure 4 is from a well drilled in Beckham County, Oklahoma. The well log shown starts at a depth of 2,980 feet. From 2,980 to 4,040 feet "granite" wash and greenish shale ("basic detritus") was encountered. The well then encountered a dark colored rock at a depth of 4,040 feet; fragments of this rock were identified by thin-sections as a member of the gabbro clan. It is composed of phenocrysts of labradorite and titaniferous augite in a fine grained matrix of the same minerals. This type of rock continued for 935 feet and there a light colored, medium crystalline hornblende "granite" was encountered. The "granite" in the samples is so

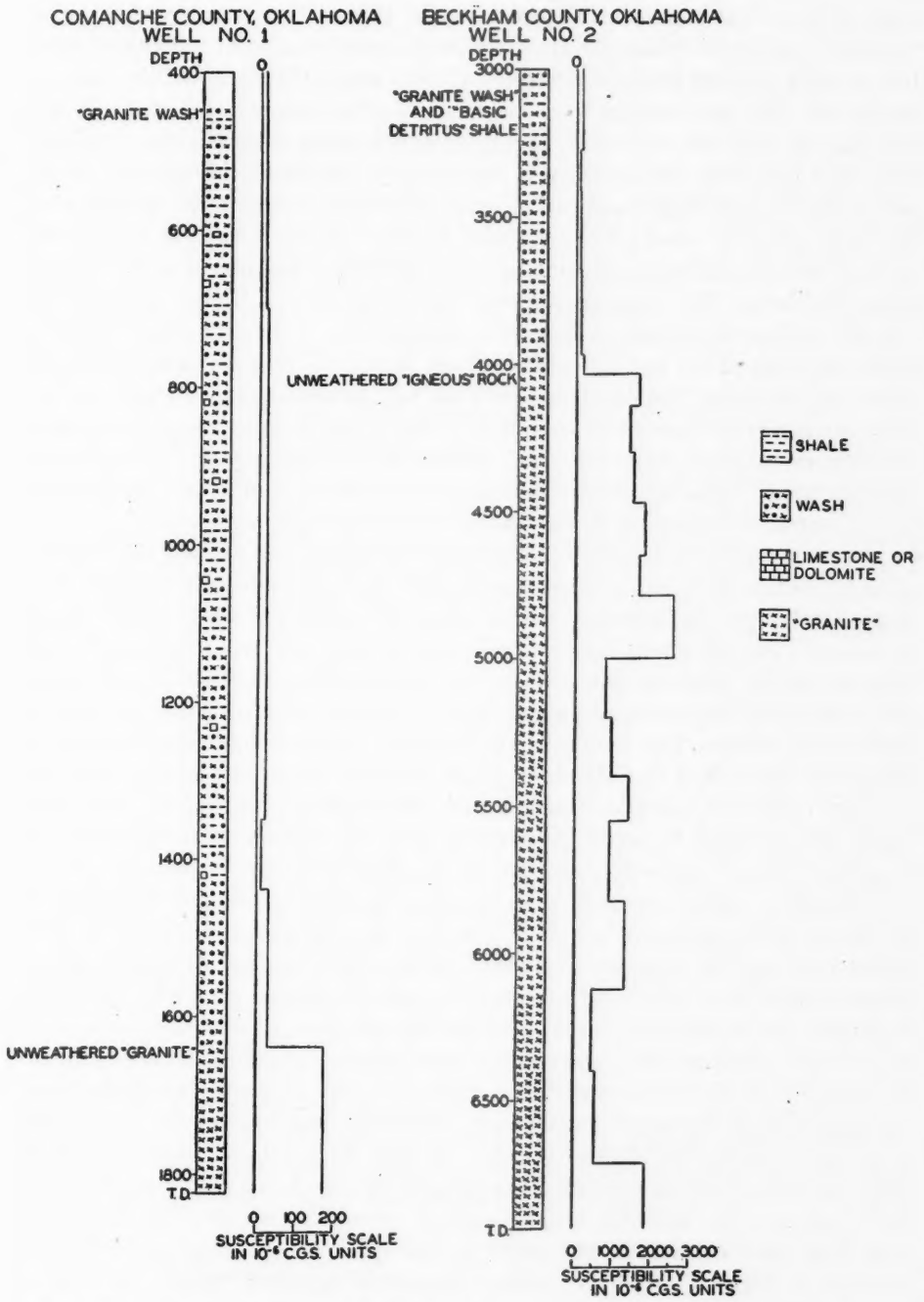

FIG. 4. Magnetic susceptibility and sample logs of portions of two southern Oklahoma wells, illustrating increase of susceptibility at depth fresh igneous rock is encountered.

finely ground that a positive identification by thin-section is not possible. This "granitic" rock was drilled for approximately 1,900 feet and at a depth of 6,720 feet, a dark colored fine grained rock of high magnetic susceptibility was encountered. The drill cuttings were too small to permit preparation of a thin section but the rock was tentatively identified as belonging to the diabase or gabbro clan. The magnetic susceptibility of the samples was the deciding factor in determining the rock below a depth of 4,040 feet to be unweathered igneous rock and not "granite" wash. The "granite" in the "granite" wash is a very fine grained rock containing graphic intergrowths of feldspar and quartz and accessory mineral chlorite. The fragments appear quite "fresh" and it was expected the "wash" section would have a magnetic susceptibility higher than usual because of the presence of the greenish shale ("basic detritus") that was included in the laboratory samples. The depth at which the well passes from the "wash" section into unweathered "basement complex" is immediately apparent by a marked increase in magnetic susceptibility. There was no difficulty in distinguishing "granite wash" in the upper section from unweathered "granite" by casual microscopic examination because of the presence of the "greenish shale" beds.

Figure 5 shows the sample logs and magnetic logs of two wells drilled in Gray County, Texas. Well No. 1 penetrated 90 feet of arkosic dolomite and red shale immediately over the "granite" wash section. This 90 feet of section is not shown on Figure 5 but has a very low magnetic susceptibility and remanent magnetism. The 225 feet of solid "granite" wash was encountered at a depth of 2,610 feet. This consists of fragments of quartz, light to slightly pink feldspar and a minor amount of chlorite. The unweathered "granite" was encountered at a depth of 2,835 feet and drilled to a depth of 3,198, the total depth of the well. The drill cuttings consist of quartz, orthoclase and albite feldspar and biotite. The fragments are too small to permit preparation of a thin section. Both the remanent magnetic log and magnetic-susceptibility log show a marked increase at a depth of 2,835 feet. This depth marked a change in the drilling rate and is considered as the top of unweathered "granite." Usually a remanent log is not made on wells where only drill cuttings are available because it is necessary to make separate measurements on a very large number of fragments before a good average for the formation can be obtained. Because of the time required to make a remanent log of several formations, the remanent logs have not been used to date for separation of "granite" wash from unweathered "granite." The magnetic susceptibility of the unweathered "granite" encountered from 2,835 feet to a depth of 3,000 feet is somewhat lower than is common in this area. This determination may be in error because of contamination of the samples by the caving of the upper "granite"-wash section. Well No. 2 encountered "granite" wash at a depth of 2,630 feet. The wash consists of fragments of light pink feldspar, quartz and minor amount of chlorite. All of the mineral fragments appeared "fresh." The top of the unweathered "granite" is placed at a depth of 2,710 feet and was penetrated 414 feet. The samples were too fine to permit preparation of a thin section, but

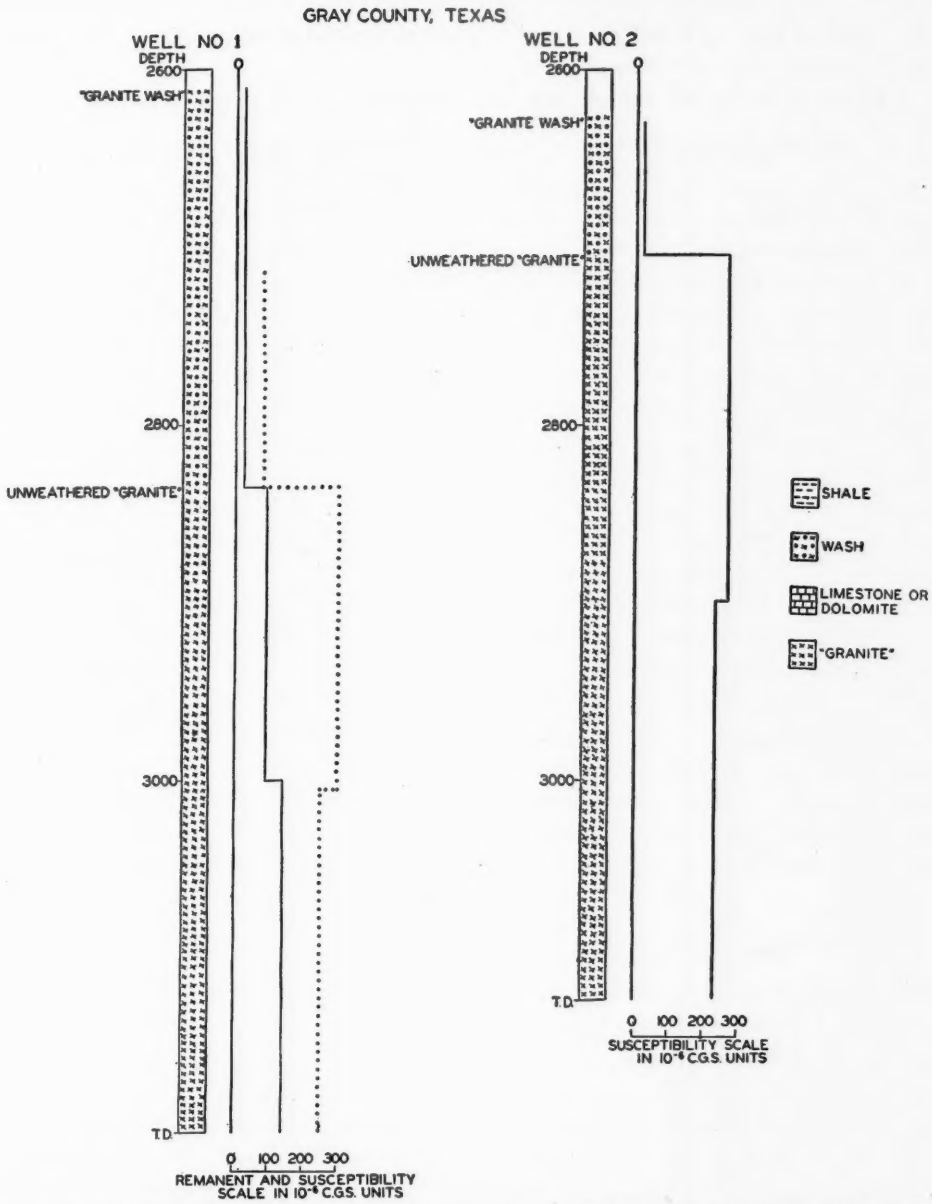

FIG. 5. Magnetic susceptibility, remanent magnetism, and sample logs of portions of two wells in Gray County, Texas, illustrating increase of susceptibility and remanent magnetism at the depth at which unweathered "granite" is encountered. (Remanent log dotted.)

the mineral constituents are quartz, orthoclase and andesine feldspars, minor amounts of hornblende and epidote. The mineral assemblage of the "granite" wash and "granite" are quite different. The magnetic susceptibility of the "gran-

ite" wash is low (24×10^{-6} c.g.s. units) and the unweathered "granite" has a susceptibility of over ten times as great.

Figure 6 shows the sample logs and magnetic logs of two wells; Well No. 1

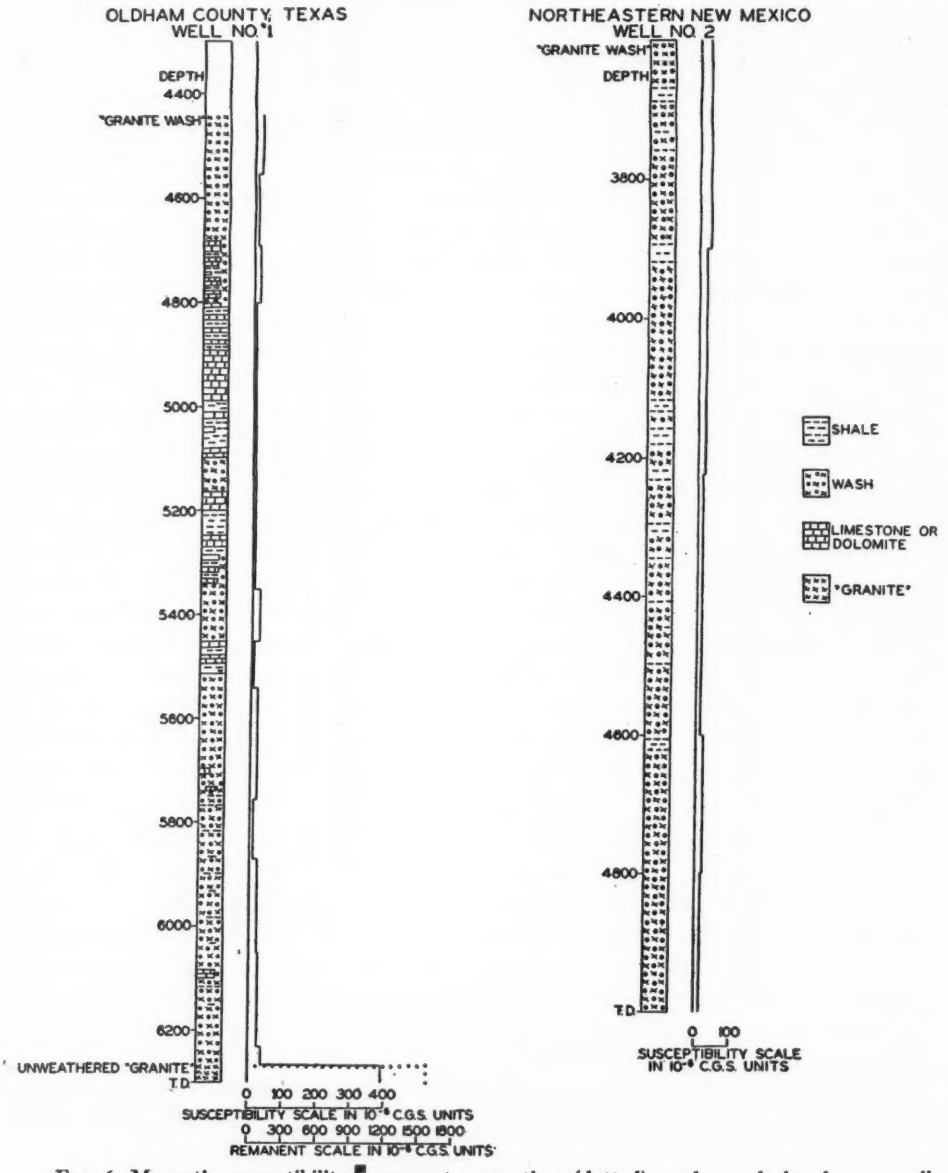

FIG. 6. Magnetic susceptibility, remanent magnetism (dotted), and sample log from a well in Oldham County, Texas, (Well No. 1), which encountered unweathered "granite." On the right, susceptibility and sample log from a well in northeastern New Mexico evidencing lack of penetration of unweathered "granite." Note difference in susceptibility and remanent scales on log of Well No. 1.

located in Oldham County, Texas, and Well No. 2 located to the west in the Eastern part of New Mexico. Well No. 1 encountered approximately 1,800 feet of "granite" wash interbedded with small amount of limestone, dolomite and red and green shale, The upper 1,400 feet of the "wash" section is composed of detritus from a coarse-grained "granite." A core from the upper portion of this section was a "conglomerate" containing "granite" pebbles or fragments as large as an inch in diameter. These pebbles are "granite" composed of coarsely crystalline quartz and light to pink feldspars and black biotite-like mica. The feldspars show more "weathering" than does the mica. The lower 400 feet of the "wash" section is composed of a fine to medium crystalline "granite" with intergrowths of quartz, pink feldspars and chlorite. The unweathered "granite" is composed of 59 percent pink orthoclase feldspar, 40 percent quartz and a minor quantity of chlorite. The rock is a member of the granite clan. The magnetic susceptibility of the 1,800 feet of "wash" section is very low compared to the susceptibility of the unweathered "granite," which has a susceptibility of 390×10^{-6} c.g.s. units. The remanent magnetism of the granite wash section tested is below 50×10^{-6} c.g.s. units, but the unweathered "granite" has a remanent magnetism of 1600×10^{-6} c.g.s. units. Well No. 2, located in New Mexico, we do not believe encountered unweathered "granite" or "basement," but drilled a long section of "granite" wash. The "granite"-wash section of over 1,400 feet encountered in this well consists of fragments of pink feldspars, quartz and a minor amount of chlorite. In the upper part of the section, red shale was apparently interbedded with the "granite" wash. In the lower part of the wash section fragments of finely crystalline "granite" are abundant. They are composed of intergrowths of quartz and feldspar. The magnetic-susceptibility log shows that the entire drilled section is low magnetically. A comparison of this log to the log on the same Figure 6, shows that the well probably did not encounter unweathered "granite."

RELATION OF SUSCEPTIBILITY TO REMANENT MAGNETISM

Magnetic susceptibility may be considered largely as a characteristic feature or primary property of a rock while the remanent magnetism may be considered largely to be a result of the history of the rock. An igneous rock of high susceptibility may have a high remanent magnetism; also a rock of medium susceptibility may have a high remanent magnetism. Only from a few wells were samples of the proper size obtainable, representing various types of igneous rock, justifying both remanent and susceptibility determination. Figure 7 shows the magnetic logs on a well located in Nebraska that drilled approximately 1,100 feet of "basement complex." This 1,100 feet of section included a variety of igneous and metamorphic rocks. The susceptibility chart is shown by a crossed line area while the remanent magnetism is a heavy solid line. The sample that has the highest magnetic susceptibility does have the highest remanent value, but the total correlation between the two logs appears very poor. This is illustrated by the remanent curve crossing the susceptibility curve. Figure 7 indicates that a rock of

high susceptibility has only a better chance of having a high remanent magnetism. The remanent figure is not as accurate as the susceptibility figure on this well because only fragments of the rock were available for remanent determination and it is always a question as to how many fragments must be measured before the results should be considered as representative of the formation.

CONCLUSIONS

The "granite" wash collected from localities in the Wichita Mountains of Oklahoma where it was possible to be reasonably sure of the original source of the

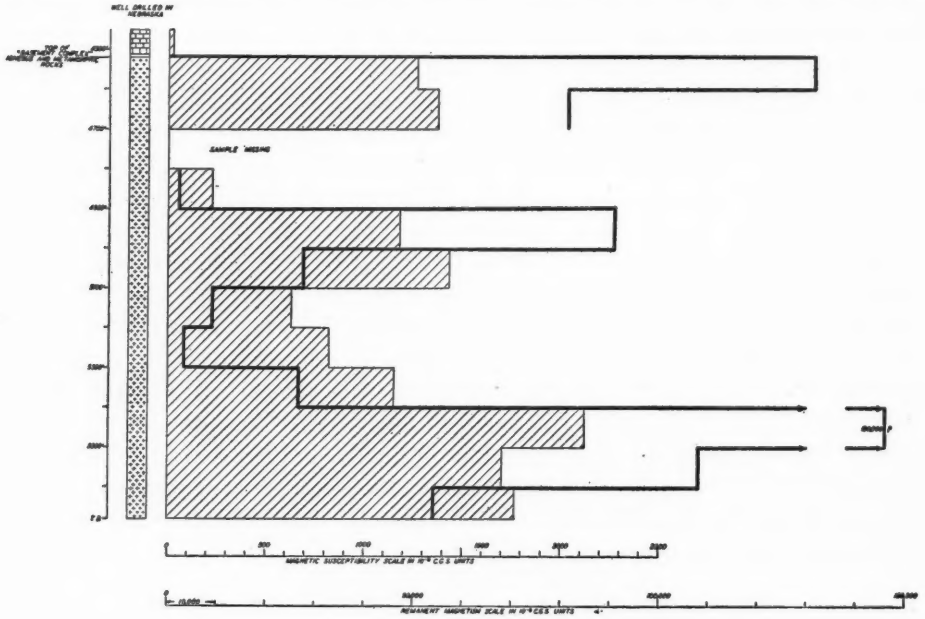

FIG. 7. Remanent magnetism (solid line) and magnetic susceptibility (hachured area) of a portion of a well in Nebraska which penetrated a variety of igneous and metamorphosed rocks, illustrating low order of correlation between these two magnetic properties.

wash, shows that "granite" wash has a much lower magnetic susceptibility than the unweathered "granite" from which the wash was derived. Also the samples of unweathered "granite" crushed into small fragments to resemble "wash," upon exposure to weather showed a decay of magnetic susceptibility and a marked decay of remanent magnetism in a short period of time. The above data are in agreement with the empirical data shown by the magnetic logs of wells that also have reasonably good geological data as to the exact top of the unweathered "granite." The magnetic logs show that solid "granite" wash has a lower magnetic susceptibility and remanent magnetism than the underlying unweathered "granite." From these data it is reasonable to conclude that "granite" wash may be differ-

entiated from unweathered "granite" by suitable magnetic measurements.

The data obtained from exposing unweathered "granite" to weather showed that the remanent magnetism decayed at a much faster rate than the magnetic susceptibility. Data from other types of "granites" might well change the decay rate that was determined from only one "granite."

The magnetic logs show that the magnetic susceptibility of a "granite" may not indicate the amount of remanent magnetism of a "granite." A "granite" having a good magnetic susceptibility may or may not have a very high remanent magnetism.

The magnetic data show that "granites" or the same "granite" from adjacent areas, having apparently the same mineralogical composition, may have very different magnetic properties.

The data from the Wichita Mountains of Oklahoma show that a large amount of magnetic data must be obtained before it is possible to generalize the magnetic properties of a "granite" mass.

The magnetic logs of wells illustrate certain possible errors that must be considered in using the magnetic properties in differentiating "granite" from "granite" wash. First, the top few feet of the solid "granite" may be slightly weathered and thus result in magnetic determinations lower than is correct for the unweathered "granite." Second, part of the material associated with the "granite" wash may have been derived from a more magnetic igneous rock than the underlying "basement." The most common case of this is the "basic detritus" that results in the formation of greenish colored shale beds. Difficulty in the separation of this type of material has never occurred because casual microscopic examination indicates the wash is interbedded with "shales" and there is no question as to the possibility of the rock being unweathered "granite." The same statement may be said of the presence of magnetic sands ("black sands.") But determination based on only a magnetic log might result in an error. Magnetic sands ("black sands") and "basic detritus" both usually have high magnetic susceptibility. Third, there is a possibility of encountering a "granite" of very low susceptibility which would not be possible to separate from a "granite" wash of low susceptibility. To date no unweathered "granite" encountered in a well, having as much as 50 feet of section to test, has resulted in a determination as low as the common "granite" wash. No "granite" wash tested to date, not mixed with "basic detritus or magnetic sands ("black sands"), has had a magnetic susceptibility as high as 50×10^{-6} c.g.s. units.

ACKNOWLEDGMENT

The writers are deeply grateful to R. Clare Coffin, under whose direction the work was carried on. Dr. Joseph A. Sharpe was largely responsible for designing the instruments and also worked with the writers in the early states of the project and gave many helpful suggestions on the manuscript. We wish to express our appreciation to the Stanolind Oil and Gas Company for permission to publish this paper.

THE GULF AIRBORNE MAGNETOMETER*

R. D. WYCKOFF†

ABSTRACT

Airborne-magnetometer operations involve two basic problems: (1) measurement of the magnetic-field intensity; (2) navigation of the aircraft to provide the desired profile configuration and accurate mapping of the profiles flown. Currently the navigation and mapping presents the most serious problem if the operation is to be made completely airborne. A brief outline of the magnetometer instrumentation is presented, together with a discussion of the mapping problem. Examples of results are presented.

INTRODUCTION

The Gulf Airborne Magnetometer is, as yet, too new to permit a complete and thorough discussion of its instrumentation or of the operational aspects of an airborne survey. This arises from the fact that while the initial developmental work antedates the war, it was not until the close of the war that Gulf personnel and laboratory facilities could be released for active development of a magnetometer-type instrument suitable for geophysical reconnaissance surveys. However during the war, effective use was made of similar detector-type equipment and intensive developmental work was carried on by others. Thus without a brief outline of the history of this wartime development, the present discussion of the airborne magnetometer would be incomplete.

The practicability of precision airborne magnetometric observations arises first of all from the fact that the field intensity to be measured is independent of motional accelerations of the point of measurement in contrast, for example, with the gravitational field wherein motional accelerations are indistinguishable from the acceleration of gravity which is to be measured. Thus, as might be expected, the idea of an airborne magnetometer to increase both the speed and value of magnetic surveys is quite old having been mentioned occasionally in the literature for more than a decade. On the other hand, in spite of adequate incentive, actual development of such a device was completely frustrated by the lack of suitable instrumentation. For prior to 1941, the only available magnetometers having adequate sensitivity for general exploration work were those in which the instrument itself was highly sensitive to motional accelerations, as in the Schmidt magnetometer where the magnetic forces are actually balanced against gravitational forces. The suggested airborne operations were, therefore, quite impractical from the viewpoint of geophysical mapping.

With the view of designing a magnetically sensitive element which might alleviate this situation, V. Vacquier investigated the properties of iron-cored devices which had long been used in certain applications where great sensitivity

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was not required. Such magnetically sensitive devices were inherently devoid of acceleration influences because of the absence of moving parts but their sensitivity was far below requirements. By 1941, however, he had succeeded in developing an element of the flux-gate type having a very high sensitivity and a physical form amenable to the airborne application. At about this time, the war menace had become increasingly alarming, and effort was immediately concentrated on the possible use of the new element as an airborne submarine detector and as the "influence" member in submarine and land mines.

After preliminary work demonstrating that the sensitivity attained by the new element was sufficient to detect a submerged submarine at a reasonable distance, support of the project by N.D.R.C. was obtained and the problem of orientation stabilization was attacked by the then most expedient means in order to establish the practicability of airborne operation with the least possible delay. The first relatively crude orienting system successfully demonstrated the practicability of the scheme. In fact, the experiment was rather quickly followed by the successful detection and disposal of an enemy submarine in an operational test flight of this early experimental model in December, 1942. This first successful tactical operation served two purposes. First, it proved the practicability of the stabilized magnetometer-type detector and thus permitted an immediate concentration of effort on this type of device as against other magnetic methods which had not attained real success. Second, and equally important, it resulted in an immediate and vastly expanded program of development on the part of N.D.R.C. Thus arose the Airborne Instruments Laboratory at Columbia University under N.D.R.C. where a very creditable piece of work was done in further development and design and from which arose the final service model or M.A.D. During the latter interval, Gulf's activity under N.D.R.C. direction and in accordance with Navy request was confined to duplicating the original experimental model in order to provide a detector for search use until a more serviceable type was available. During this transition period in 1943, the Gulf personnel were transferred to other war projects and the magnetometer development could not be revived until the close of the war.

Concurrent with the N.D.R.C. activity, work underway at the Naval Research Laboratory and associated Bell Telephone Laboratories resulted in a basically similar apparatus. This unit, also designed for anomaly detection rather than magnetometric mapping, was suitably modified during the war and flown in cooperation with the U. S. Geological Survey on geophysical surveys, evidently with the view to expedite exploration of certain Naval petroleum reserves.

Here we should distinguish between the magnetic-anomaly detector and the magnetometer, for, while the sensitive elements may be identical, the associated equipments differ because of the different character of the data desired. In the anomaly type, such as the submarine detector, the very weak but sharp anomaly caused by an extremely local magnetic disturbance arising from a steel hull must be resolved from the broader geological anomalies and recorded as nearly as

possible distinct from all other disturbances. Since a traverse is made at relatively constant speed and the field intensity is observed continuously, geological anomalies being of relatively large areal extent will be indicated as a long-period disturbance of possibly relatively large amplitude, whereas the ship or submarine anomaly will be of low amplitude and very short duration. Thus, by the simple expedient of designing the recorder system to pass short-period disturbances while suppressing those of long period, the submarine's "signal" may be recorded quite effectively isolated from all long-period or normal magnetic variations. This indicates clearly that the design of the anomaly-type recorder precludes its use for magnetometric surveys unless the recorder system is reconstructed so as to pass all lower frequencies. In fact, it must be able to record steady values of the magnetic field if it is to be of value in geophysical mapping.

Since the basic design of the recording magnetometer is dictated by accuracy requirements, it is pertinent first to consider this phase of the problem. We may assume for example that the average magnitude of the earth's field to be measured is on the order of 0.5 gauss or 50,000 gammas. We may further assume that it is desired to map anomalies whose magnetic relief is on the order of 10 gammas. This leads immediately to a recording accuracy of about 1 gamma or 1/50,000 of the total field. Since no indicating or recording instrument may be read with such accuracy, it is evident that means must be devised whereby a major and accurately known portion of the magnetic field is nullified, leaving only a residue to be measured and recorded. Thus, the problem is in principle, identical to the well-known deflection potentiometer in which the major portion of the voltage to be measured is bucked out by the potentiometric circuits and a small residue is read on a deflection-type instrument. Such a solution of the recording magnetometer problem results in some complexity in the equipment, but places it within the realm of possible achievement.

INSTRUMENTATION

The Magnetometer Element.—The heart of the magnetometer is, of course, the magnetically sensitive element upon which the externally applied magnetic field reacts with the production of a "signal" voltage which may be measured and recorded in terms of the intensity of the applied field. It must be sufficiently sensitive to produce a measurable change in signal level when the applied field is changed by 1 gamma, and it must be free of spurious effects due to motional accelerations if it is to be used as a continuously recording device in a moving vehicle or aircraft. Such a detector is now available among the class of ferromagnetic-cored devices recently broadly designated as "Flux-gates." Here, it is pertinent to discuss very briefly the general principles involved in the flux-gate magnetometer.

It has long been known that, because of the nonlinearity of the magnetization curve of ferro-magnetic materials, coils having iron cores change their effective a.-c. reactance when a unidirectional magnetic field is superposed on the core. Not

only is there a change in effective reactance due to the presence of the d.-c. field, but there results a distortion of the a.-c. wave form derived from such reactors. Now in the case of ordinary cores, the earth's field intensity is too low to produce any great change in such a reactor since the permeability of the core is relatively low. However, this is not true of reactors having cores of special high-permeability alloys, and in such devices, the earth's field may induce magnetizations which are a very appreciable part of the total saturation intensity. As a result, such reactors are sensitive to ambient fields of relatively low intensity and have been

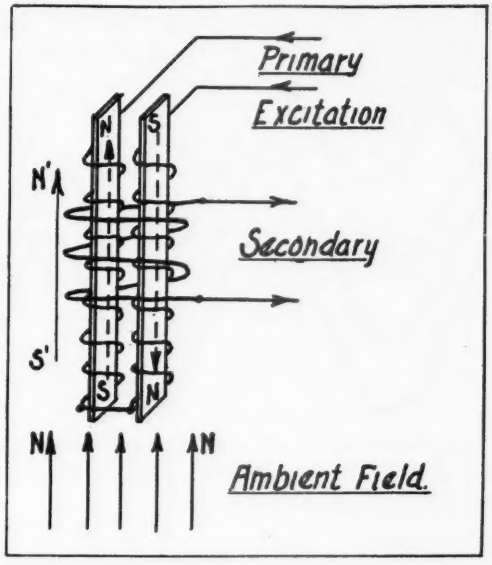

FIG. 1. Schematic drawing of Vacquier magnetometer element. One form showing double core, opposed primaries and single secondary. Other modifications produce identical results.

used as field measuring devices. Typically, such devices make use of the distor tions in the a.-c. wave shape, which through the action of suitable auxiliary rectifier circuits in conjunction with a d.-c. meter exhibit the ambient field effect as a deflection of the meter.

V. Vacquier's efforts to increase the sensitivity of such devices for magnetometer applications led to the present Gulf[1] element. Its superior sensitivity is derived entirely from the action of the element as its core enters the saturation region—the sharp knee in the *B-H* curve—when driven there by a suitable source of excitation. As will become evident on careful study, this element may take a variety of forms; it is perhaps most easily understood by consideration of the form shown schematically in Figure 1.

Two thin strips of high permeability material, such as mumetal are each

[1] V. Vacquier, U. S. Patent No. 2,406,870, September 3, 1946.

wound with identical exciting windings and connected to a common source of cyclic excitation in such manner as to produce magnetizations in opposite directions in the two parallel strips. (It will be evident that it would be advantageous to close the air gaps at the ends, thus forming a rectangular closed-core circuit.) Now, since the induction fields of the cores are equal in magnitude and opposite in direction, no voltage will be produced across the terminals of the secondary winding which surrounds both cores. However, in the presence of the indicated ambient field, it will be noted that the polarity $N'S'$ induced in the parallel legs of the element is in one leg aiding and in the other opposing the cyclic excitation. Thus while the cores may be identical in all other respects, there will be a time lag in the magnetization cycle of one leg as compared with the other, and this

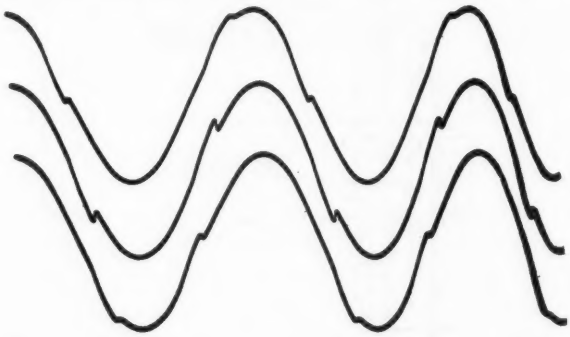

FIG. 2. C.-r. Oscillogram. Voltage across one primary of arrangement of Figure 1 showing phase shift of saturation discontinuity with changes of ambient magnetic field. Middle trace is zero ambient field. Other traces strong ambient field reversed in sign.

time lag will depend on the strength of the ambient magnetic field. However, this effect of the magnetic bias can be made evident at the secondary only in the presence of a nonlinear charactersitic in the magnetization properties of the core material. Actually, in this element we have present not only the strong nonlinearity characteristic of ferro-magnetic material but we accentuate the nonlinearity by cyclically driving the cores well beyond their saturation point. The middle curve of Figure 2 shows the distorted voltage observed across the exciting coil of one leg of the element when the ambient field is zero. The wave form is the sum of the IR-drop in the coil due to a sinusoidal exciting current, and the induced or back e.m.f. resulting from the induction field of the core. The sharp discontinuity in the voltage wave occurs at the instant the core enters the saturation point on both the positive and negative portions of the excitation cycle. The upper curve shows the shifts in phase of these discontinuities when the core is subjected to a strong ambient d.-c. field, and the lower curve shows the reversal of the *phase shifts* when the polarity of the ambient field is reversed. Clearly, when the ambient magnetic field is aiding the magnetization of the exciting current, the saturation point is reached earlier in the excitation cycle, and when the ambient field

opposes the excitation, saturation is not reached until later in the excitation cycle. At the instant of saturation, magnetization of the core ceases to increase and the induction voltage drops to zero; i.e., the observed voltage drops abruptly to the *IR*-value, giving rise to the discontinuities shown in Figure 2, where the phase shifts due to an ambient field are also clearly shown. However, the phase shifts in these oscillograms are exaggerated by exposing the cores to a relatively strong ambient field in order to make clear the phase-shift phenomena.

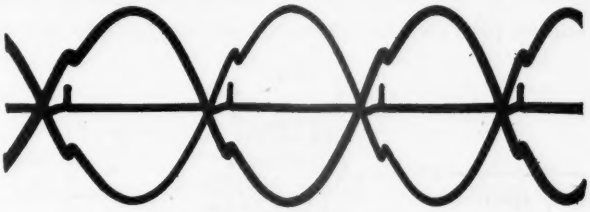

FIG. 3. C.-r. Oscillogram. Outer traces showing voltage across each primary. Middle trace of secondary voltage shows cancellation of all but voltage pip due to phase difference of saturation discontinuity in the two cores due to bias imposed by small ambient magnetic field.

In Figure 3, the voltage across each of the two coils of Figure 1 is shown for the case where the ambient field is of such small intensity that visual examination of the two curves fails to resolve the phase shift. However, the third curve showing the voltage developed across the secondary winding of Figure 1 clearly indicates the equality of the induction fields of the two halves of the core except at the saturation discontinuities where the momentary unbalance due to phase shift gives rise to the sharp voltage "pip" in the secondary winding.

Figure 4 shows the secondary voltage "pips" of Figure 3 slightly amplified. It may be shown that the peak value or energy content of these pips is propor-

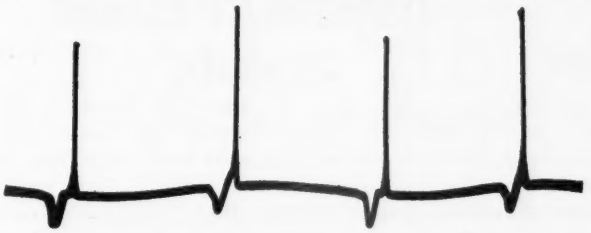

FIG. 4. C-r Oscillogram. Secondary output voltage (middle trace of Fig. 3) amplified. Pip height is proportional to ambient magnetic field.

tional to the ambient field intensity within reasonable practical limits. Moreover' the polarity of the pips reverses with reversal of the field, although in going through zero, the useful pips are submerged within the low-level noise or "hash" evident near the main pulse in Figure 4. To avoid this difficulty at zero field, the elements may be deliberately unbalanced electrically by a suitable shunt across one of the exciting windings. The result of this unbalance is the reversal of one of

the pulses so that both positive and negative "pips" appear (one at each half of the excitation cycle), and they will be of equal magnitude in zero ambient field. If now the ambient field be increased, the positive pips will increase and the negative pips decrease by equal amounts while the reverse performance will result if the ambient field is reversed in polarity. Thus, if the changes in ambient field are not excessive, the amplitude of the pulses may change but need not pass through zero even with a reversal of the ambient field.

Summarizing, it may be said that while the circuits used or the type of excitation may be modified provided the cores are driven beyond the saturation knee

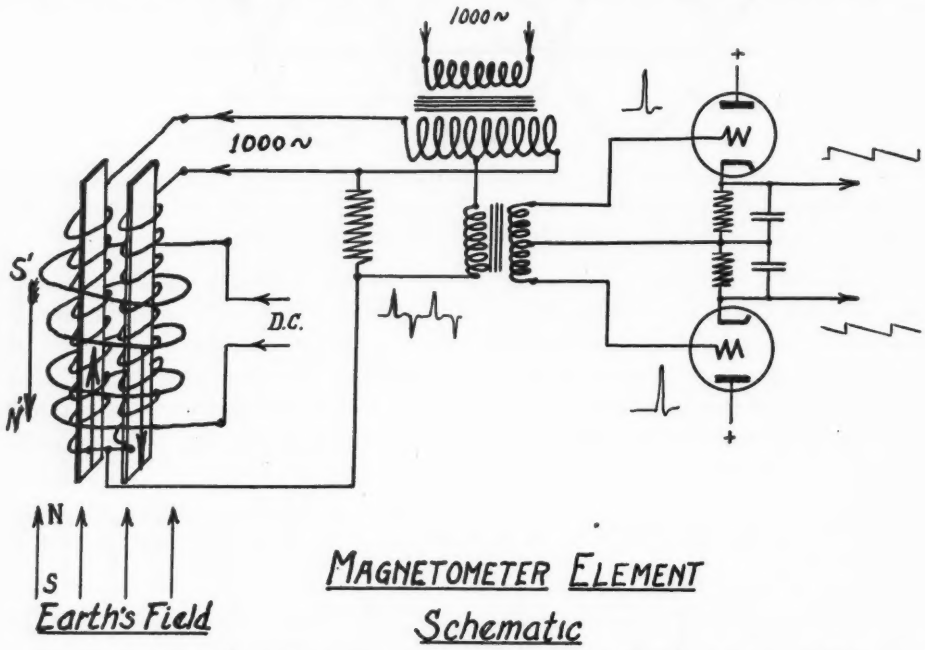

FIG. 5. Schematic diagram of magnetometer detector circuit. Secondary voltage as in Figures 3 and 4 is here obtained from modification of primary circuits equivalent to single secondary. Secondary winding is shown as Helmholtz compensating means producing bucking field N'–S'.

or even the physical construction of the core may be changed to suit the purpose at hand, in principle, the element generates sharp voltage pulses in the output circuit, the peak value of which is a measure of the ambient magnetic field. It remains only to devise a suitable peak voltmeter and associated recording equipment to complete the recording magnetometer.

Detection and Recording of Pulses.—Figure 5 shows a diagram of a suitable arrangement. Here a 1,000-cycle oscillator is used to provide excitation of the two cores. The output pulses are derived not from a secondary winding but via the pulse transformer inserted in the "neutral" connecting the midtap of the exciting transformer and the midpoint of the exciting windings on the element. This is in

effect identical to the use of a secondary winding but may be advantageous for certain circuit arrangements or expedient design.

The pulses from the secondary of the pulse transformer are fed to the grids of an infinite-impedance detector where the output voltage is derived across the high-resistance cathode circuit whose time-constant is relatively long compared with the 1,000-cycle repetition rate of the pulses. Thus, between ground and cathode of each detector appear a d.-c. voltage proportional to the peak voltage or energy content of the pulse with a residual 1,000-cycle saw-tooth component superposed. After filtering to eliminate the 1,000-cycle saw-tooth component, a relatively pure d.-c. is available. The d.-c. component at this point is of the order of 10 to 12 volts, and evidently, if the positive and negative pulses from the element are of equal amplitude as would be the case if the magnetometer element were in zero ambient field, the voltages appearing at the cathodes of the differential-detector tubes will be identical.

A very high impedance voltmeter connected across the two detector cathodes would serve to measure and record the differential voltage which is proportional to the ambient field intensity at the magnetometer element. However, in order to match the input impedance of commercial recorders, a differential cathode-follower stage is interposed between the detector and the recorder. The output circuit of the cathode followers includes suitable attenuators whereby the scale range of the recorder may be varied to suit the magnitude of the anomalies being mapped, and the sensitivity of the recorder may be adjusted to proper sensitivity or calibration. The recorder used in the Gulf equipment is a Leeds-Northrup Speedomax designed for 24-volt aircraft use and has a full-scale sensitivity of about 8 millivolts. It is of the potentiometric self-balancing type capable of restoring balance over the full 10-inch scale length in about 1.2 seconds. Figure 6 is a schematic block diagram of the recording magnetometer.

It is of some interest to note that except for the step-up ratio of about 10/1 in the pulse transformer, no voltage amplification is involved between the magnetometer and the recorder. On the contrary, while the amplification of the detector circuit may approach unity, that of the cathode follower is considerably less than unity with the result that the voltage is actually attentuated considerably before reaching the recorder.

The recorder range-selector in the detector unit is calibrated to provide a full scale of 300, 600, 1,200, 3,000, 6,000, and 12,000 gammas, at the recorder. Thus, with 600 divisions on the recorder chart, it is not difficult to read within 1 gamma on the 600-gamma range. It is also of interest to note that tests indicate linearity within the accuracy of the scale readings from the 300- through the 6,000-gamma range and in recent models even on the 12,000-gamma range.

Nullifying the Earth's Field.—As already mentioned and as will be evident from the foregoing discussion, it is necessary to provide means whereby any desired portion of the earth's field may be accurately nullified at the magnetometer element. Thus, with the recorder range set at 600 gammas, the uncompensated

portion of the earth's field cannot exceed 600 gammas or the recorder would remain off scale.

In the diagram of Figure 5, a compensating coil is shown surrounding the magnetometer element. By adjusting a direct current through this winding to the proper value, it is evident that any desired portion of the earth's field at the element may be nullified. To accomplish this, a constant-impedance network is provided through which an accurately adjusted current of constant magnitude is circulated from a suitable working battery. A decade-switching arrangement

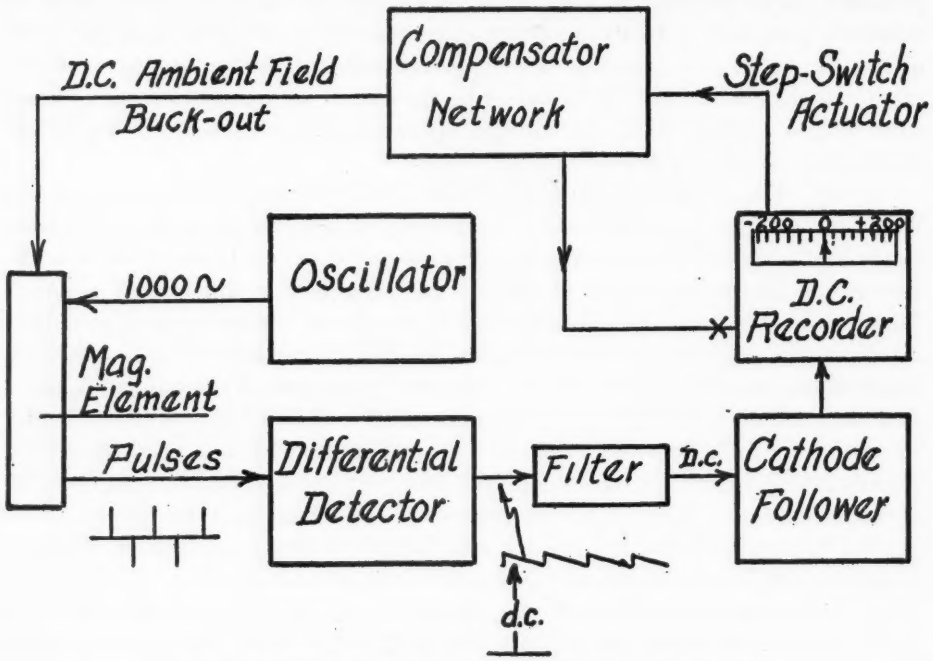

FIG. 6. Schematic block diagram of recording magnetometer.

comprising three switches serves to supply accurately calibrated increments of d.c. to the compensating coil on the magnetometer element, such that the resultant compensating field may be adjusted in steps of 250 gammas from 0 to 80,000 gammas. The steps available at each of the switches are 250 and 500, 2,000 and 10,000 gammas, respectively, and they are mechanically connected through suitable geneva-type gearing to provide continuous step-switching from a motor drive at the low-increment end of the dial. This reversible motor is automatically actuated by limit switches at the end of the recorder scale. A suitable step-range selector available in 250-, 500-, and 2,000-gamma ranges determines the total number of gammas through which the switch will automatically step once its motion is initiated by the limit switch. Thus, with the recorder on the 300-gamma range and the step selector on 250 gammas, a change in field strength causing the

recorder to go off scale will immediately actuate the step switch throwing an additional 250-gamma compensation at the element and put the recorder within range at the lower end of its scale. Similarly, with the recorder range set at 3,000 gammas full scale and the step selector set at 2,000 gammas, an off-scale reading of the meter will actuate the step switch which will continue operation until 2,000 gammas additional compensation has been imposed on the magnetometer element. Obviously, the reverse operation results from actuation of the limit switch at the low end of the recorder scale. The step selector may be set to permit automatic stepping through 250, 500, and 2,000 gammas. In addition, manually operated push buttons permit over-riding of the limit switches at any time or simply manual operation in either direction by any desired number of 250-gamma steps.

Since the total value of the earth's field is the sum of the compensated field and the residue as read on the recorder scale, the reading of the compensator dial must be marked on the recorder chart. In the present equipment, the revolutions of the step-switch drive are transmitted through suitable gearing and a flexible shaft to a printing counter mounted in the recorder, this counter recording the equivalent gamma reading of the compensator prints on the recorder chart whenever its actuating solenoid is energized. This may be done automatically at the instant before and after the compensator has stepped or at any other desired time. For ordinary reconnaissance use, such as in petroleum exploration, the present compensation stepping is sufficiently rapid. For certain special uses or in country of great magnetic relief where very rapid changes are essential, modification to control of the individual step dials and separate shafts to the printer dials may be required.

Stabilization of the Orientation of the Magnetometer Element.—We have considered briefly the salient features of the magnetometer element and associated equipment whereby the intensity of an ambient magnetic field of 0 to 80,000 gammas may be continuously recorded. A further step is necessary before the magnetometer can be used on a moving vehicle, since a sufficiently stable support must be provided to maintain the orientation of the element within the desired precision of measurement. Cursory consideration might indicate the use of gyro-stabilized reference planes, such as the horizon-gyro, thus permitting orientation of the element in the vertical and measurement of the vertical component of the earth's field as in ordinary surveys. It will be found, however, that the precision of such devices is not yet adequate. The expedient means is to measure the total field intensity whereby the element is oriented parallel to the total field vector. In this case, a small error in orientation leads to much smaller measurement errors, the latter being proportional to the cosine of the orientation-error angle. Thus, in a total field of 50,000 gammas, a 1° misorientation gives 9 gammas, and 2° gives approximately 24 gammas error in measurement.

Maintenance of the magnetometer element parallel to the earth's total magnetic vector may be accomplished by several specific types of apparatus all

identical in principle, in that the servo control is actuated by a magnetically sensitive element or array seeking to align the *plane* of sensitivity into the magnetic horizon. One form of automatic magnetic-horizon orientation involves the use of a pair of auxiliary elements of the same type used in the magnetometer. A pair of such elements mounted at right angles to each other define a plane. When this plane containing the axes of sensitivity of the two elements is parallel to the magnetic horizon, both elements experience zero ambient field and produce zero output signal. A magnetometer element mounted normal to this plane will then be oriented parallel to the total field and provide an accurate measure of its intensity. Now let the plane of the control elements depart from the magnetic horizon by a small angle. Depending on the axis of tilt, an error signal proportional to the sine of the error angle* will appear at the output terminals of one or both of the detector elements, and after suitable amplification may be applied to one or both of two servo-motors coupled to each of the two gimbals of the universal gimbal mounting supporting the magnetometer. Thus the servo-motors are supplied with actuating signals of a magnitude and sense, such as to restore their respective gimbal and detector element into parallelism with the magnetic horizon. In this method of orientation control, two magnetic detectors and associated amplifier channels are required in addition to the magnetometer element. Because of the presence of an exciting field in the operation of each element, it is then necessary that the axes of sensitivity of these three mutually perpendicular elements be adjusted and carefully maintained in this relation so that the mutual magnetic coupling between them will be zero.

In the present Gulf equipment an alternative arrangement is used whereby the magnetometer element itself provides the orienting signals which operate the two gimbal motors. At one end of the element, a rotating disc carries a small mumetal vane extending radially outward from beneath the axis of the magnetometer. This auxiliary right-angled extension converts the straight magnetometer core into an L-shaped core and shifts the effective magnetic axis in the direction of the vane radius by a small angle with respect to the normal axis of the element. In effect, with the vane rotating, the element then samples the field in a conical sweep, the axis of the cone being the axis of rotation of the vane. The rotating disc is driven at 3600 r.p.m. by a small air jet. Now when the axis of the cone is parallel to the ambient field, the element experiences a constant m.m.f. though slightly reduced because the effective axis makes a slight angle with the field. On the other hand, if the axis of the cone is tilted out of the field, the element experiences a slight variation in field intensity, the maximum occurring when the vane is pointing toward the axis of proper orientation and the minimum 180° later in the rotation when the vane is pointing in the direction of misorientation. Thus, once in each revolution of the vane, the element experiences a small a.-c. field superposed on the large steady component and in response produces pulses of correspondingly varying output. Since the disc is driven at 60 r.p.s. the envelope of the

* In contrast to the cosine of the error angle appearing at the magnetometer element.

pulses will comprise a small 60-cycle component superposed on a d.-c. average. Evidently this 60-cycle component will disappear when the magnetometer element is properly oriented parallel to the ambient field. It may also be shown that this a.-c. component is sinusoidal with an amplitude proportional to the sine of the angle of misorientation and a phase corresponding to the direction of misorientation.

In order to establish the phase of the 60-cycle misorientation voltage with respect to the axes of the gimbals a small commutator segment is carried by the vane rotor. When this conducting segment passes under a fixed brush, the grid circuit of a suitable tube is closed. The resulting "pip" is converted into a 60-cycle sinusoidal wave, and after sufficient amplification supplies the fixed or reference phase of each of two 2-phase servo-motors which drive the gimbals. Since the gimbals axes are at right angles, the reference voltage feeding the fixed phase of one gimbal motor is shifted 90° by a suitable series capacitator. Now if the misorientation voltage is amplified and fed directly to the control phase winding of each motor, the servo system will act as a phase discriminator, and each motor will operate so as to drive its associated gibmal into proper position to correct the misorientation of the magnetometer element. If the phasing of the several circuits has been properly adjusted, each servo channel will act independently of the other, and a misorientation of only one gimbal will lead to its correction without disturbing the other gimbal whose alignment was satisfactory.

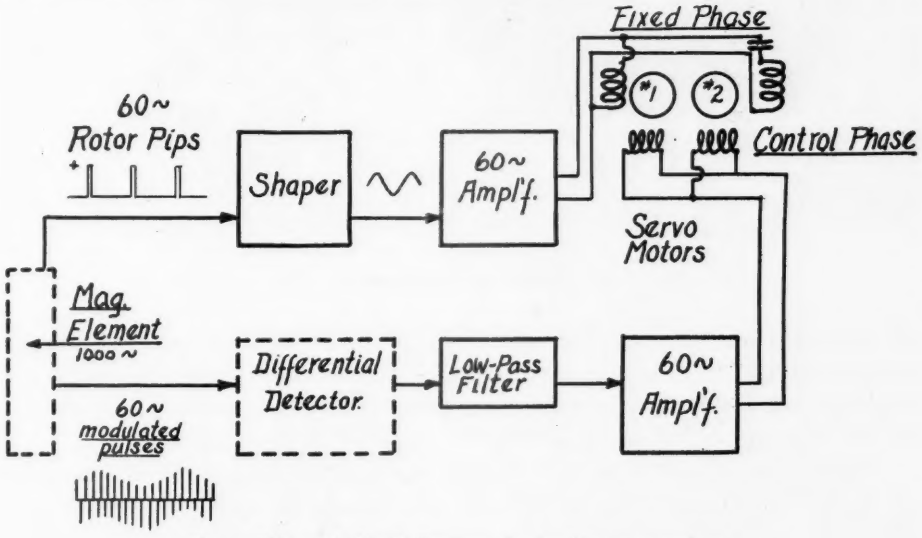

FIG. 7. Schematic block diagram of orienting servo system.

The block diagram in Figure 7 will serve to illustrate the operation of the orientation servo system in sufficient detail for present purposes. It will be noted that the "modulated" pulse signals from the element are fed to a detector com-

mon to both the recorder and the orientation circuits. Only the 60-cycle component, when present, is passed on to the modulation amplifier. On the other hand, the 60-cycle "error" modulation is filtered out along with the 1,000-cycle sawtooth residue of the pulses before reaching the cathode follower which actuates the recorder.

The photograph, Figure 8, shows the magnetometer head unit in detail. The main yoke and the universal-gimbals system are evident. The view is looking into

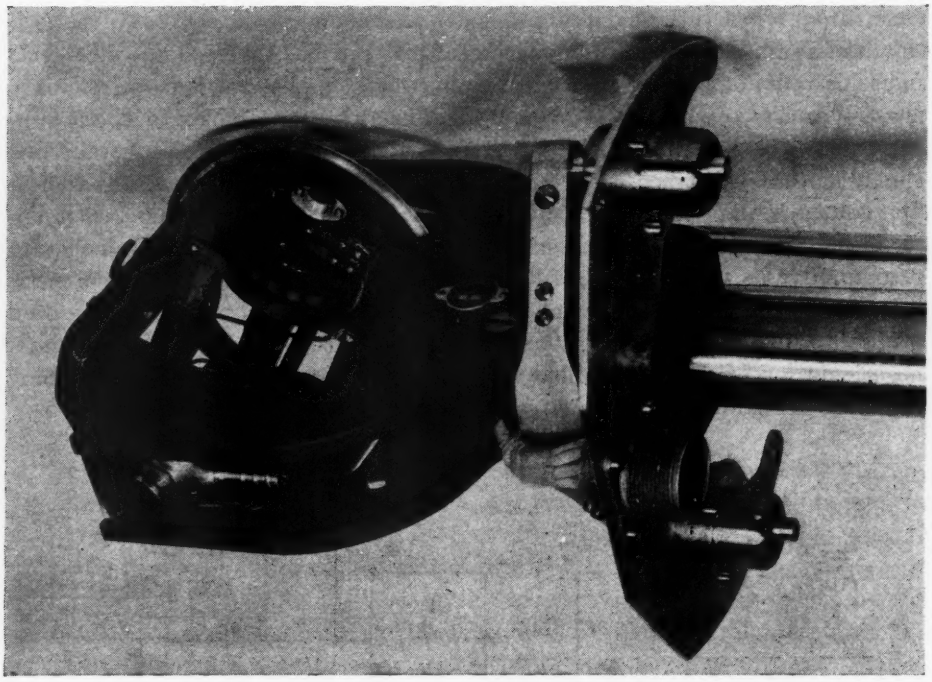

FIG. 8. Photograph of magnetometer head unit.

the bottom of the inner gimbal to show a portion of the sensitive element, the air-driven rotor, and the housing of the rotor pipper commutator. The wiring of the head unit has been omitted. Figure 9 shows the servo-motor end of the assembly including a third-motion motor for low latitude operations.

Figure 10 shows a view of the complete head unit as assembled for installation in the bird housing. The servo-motor assembly at the right is located sufficiently remote from the magnetometer element to eliminate serious magnetic disturbances. Any residual permanent or induced magnetic moments in the motor assembly may be compensated at the head by suitable compensation units on the bird housing.

Figure 11 is a photograph of the complete electronic gear. The units in the

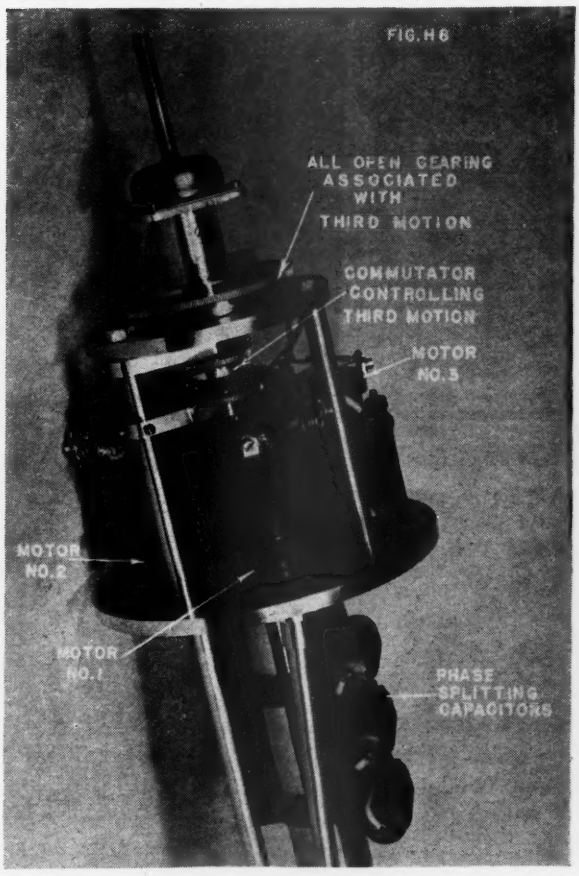

FIG. 9. Photograph of orientation servo-motor end of unit.

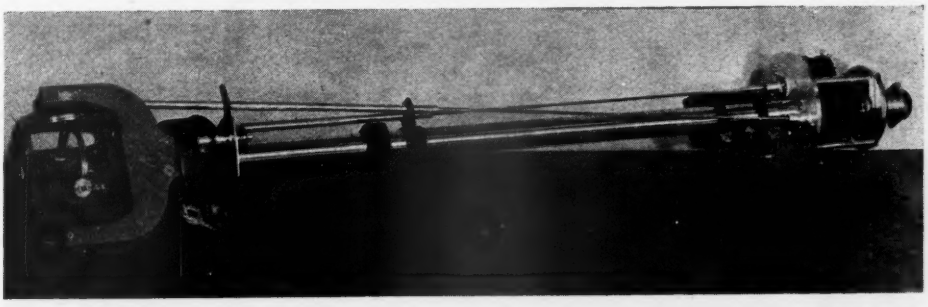

FIG. 10. Complete magnetometer head unit assembled.

rack from the top down are: Power Supply, Modulator-Synchronous Amplifier, early-model Compensator, and Detector. A Leeds and Northrup Speedomax recorder is used in conjunction with this equipment to record magnetic variations on a 10-inch chart.

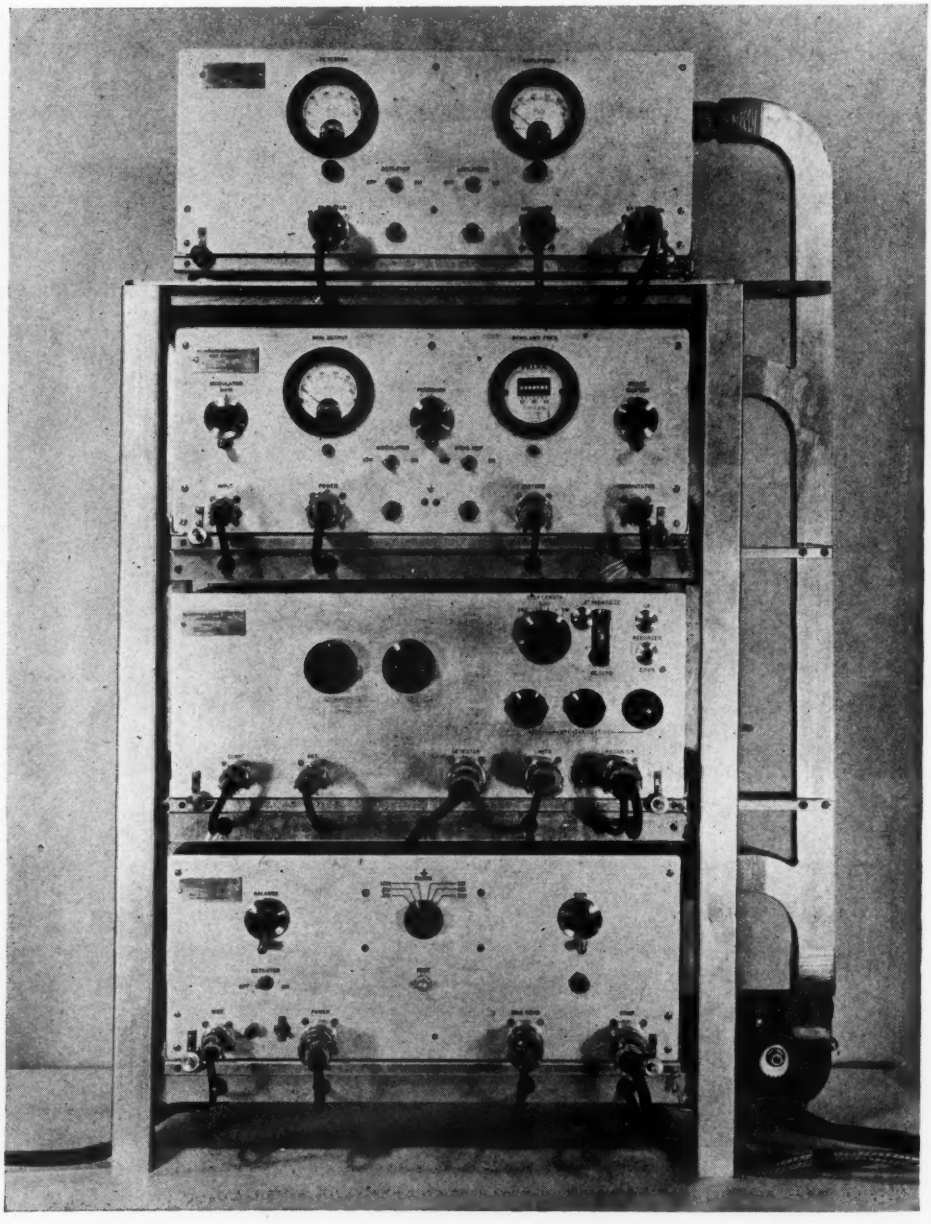

FIG. 11. Complete electronic equipment.

AIRBORNE OPERATION OF THE RECORDING MAGNETOMETER

The foregoing discussion has outlined the salient features of one form of the Gulf recording magnetometer which at present is in use in commercial operation by Gulf and licensed operators, Fairchild Aerial Surveys, Inc., and Aero Service Corporation. However, there are certain details involved in such installations that warrant brief mention.

Location of the Magnetometer Head Unit.—A major consideration in aircraft installations is the location of the magnetometer-head unit in a suitable position free of spurious magnetic effects arising from the aircraft itself. Obviously, the selection of a magnetically quiet location is far more critical than the analogous problem of a suitable flux-gate compass installation. Not only must the magnetometer be sufficiently remote from iron or steel members, such as engines, landing gear struts, control cables and the like whose permanent or induced magnetic moments may be large, but if mounted near large metallic conducting surfaces induced eddy currents due to certain motions of these surfaces in the earth's field itself will cause disturbances unless properly compensated.

In general, the extreme tail position would be sufficiently remote from engines and other ferro-magnetic parts in the forward part of the ship to avoid trouble or could be suitably compensated without undue labor. Advantage was taken of this circumstance in some of the Navy search ships by installing the magnetometer in a suitable "stinger" protruding from the tail of the ship. However, in many aircraft of even medium size the elevator and rudder control surfaces are operated by steel torque tubes of such size that excessively large magnetic gradients are encountered at the extreme tail position and even as far aft as any reasonable structural addition could carry the instrument. Moreover, the shape of the disturbing field is too complex to permit satisfactory compensation of both permanent and induced moments. The advantages of such placement of the magnetometer should, however, warrant special construction of the empennage of magnetometer aircraft at some future date.

Wing-tip installations are possible but not without special compensation to eliminate disturbances from eddy currents caused by changes of flux linkage of the wing surfaces as they assume varying attitudes in the earth's field. Moreover, vibration at the wing tips is quite severe at times, particularly when taxiing or in very rough air, with the result that the somewhat delicate servo mechanism in the magnetometer may be subjected to undue wear with resultant mechanical trouble.

To avoid such problems, in particular the compensation of stray fields which would require constant surveillance to detect changes that might occur with time, it is expedient completely to remove the magnetometer head from proximity to the aircraft. This is accomplished, as was done during the war, by towing the magnetometer in a bomb-shaped "bird" having sufficient tail surface to provide a high degree of weathercock stability. Using a 60-lb. bird, at about 140 m.p.h. the bird flies at an angular position below the ship about 45° from the vertical with some 65 feet of cable released. With a 90-lb. bird and 75 feet of cable, the

angular position is about 60° from the vertical at 200 m.p.h. Since most of the aerodynamic drag arises in the large-diameter cable, smaller weights would provide similar performance if the cable size were reduced. The present cable is about $\frac{7}{8}$-inch in diameter. The above distances provide good flight characteristics and serve to reduce stray magnetic fields from the aircraft to a negligible value.

The bird, which comprises a weather-tight housing for the magnetometer head, is of streamlined cylindrical form about 8 inches in diameter and 55 inches

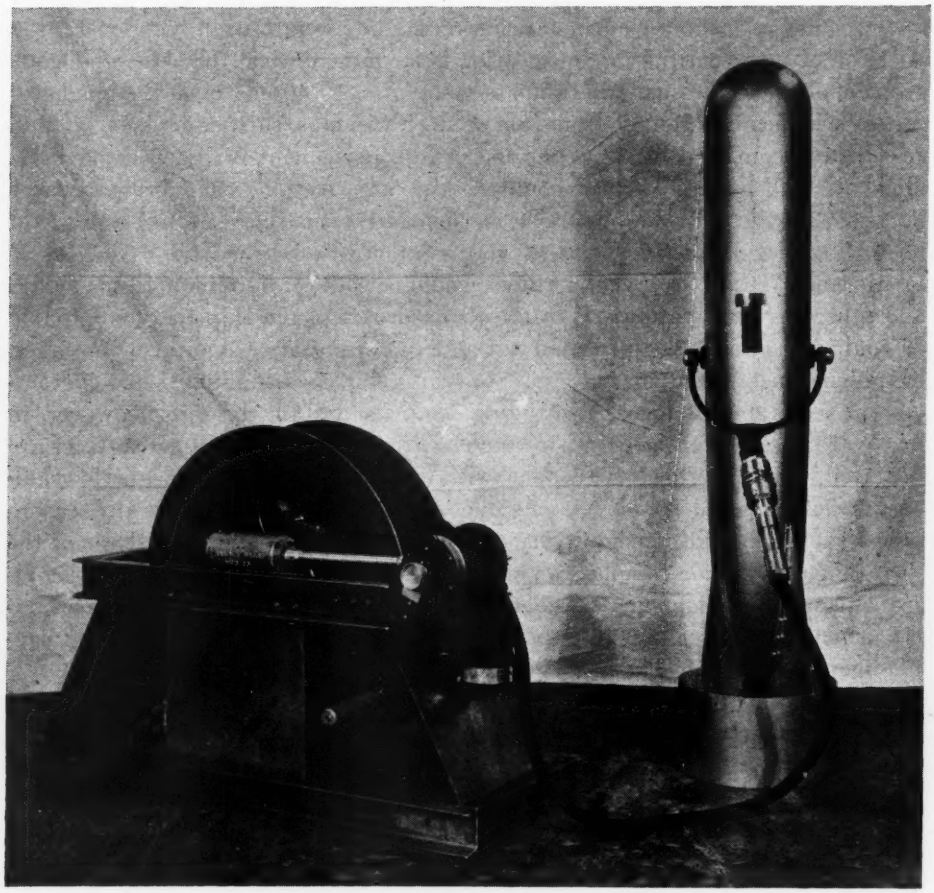

FIG. 12. Bird and reel assembly.

long overall with a cylindrical tail fin of somewhat larger diameter than the body in order to provide a good weathercock stability. The bird is suspended at the center of gravity by a suitable bail to which the cable is attached.

Cable and Hoist.—The cable is made up of 12 separately shielded conductors surrounding a $\frac{1}{4}$-inch diameter flexible aluminum conduit which serves as a con-

ductor for the flow of about 1.3 cu. ft. of air per minute at about 7-lb/in.^{2} pressure used to drive the air turbine wheel at the modulator end of the magnetometer element as previously described. The cable is sheathed with rubber which also provides a pressure-tight seal since the flexible conduit is not of itself, airtight. A suitable reel is provided in the ship to accommodate 125 feet of cable and per-

FIG. 13. Installation on Grumman amphibian "Goose."

mits easy release and retraction of the bird using an electric hoist of about $\frac{1}{4}$ to $\frac{1}{3}$ h-p. capacity. For obvious safety reasons, although requiring power for release of the bird, the reel is driven through a worm gear providing a positive lock at any position as soon as power is removed. An alternative hand crank is provided for emergency use in case of power failure. The bird and reel assembly are shown in Figure 12.

The ideal installation permits the bird to be retracted completely within the ship through suitable small "bomb-bay" doors. This is not only most convenient but allows NC licensing of the aircraft. However, since all aircraft are not already provided with the access doors in the belly of the ship and in some the installation is impractical, we have mounted the bird in a suitable rack on the side of the

fuselage and encountered no difficulty in launching or retracting the bird. Such an installation is shown in Figure 13 which shows the laboratory experimental plane—a Grumman "Goose" amphibian.

Air Pump.—The air supply for the modulator rotor on the magnetometer head is furnished via the cable from a $\frac{1}{8}$–$\frac{1}{4}$ h-p. motor-driven diaphragm pump which is capable of supplying about 2 ft^3/min. at 10-lb/in.^{2} pressure. This pump is completely free of any oil contamination which would eventually cause trouble at the rotor.

Electronic and Associated Equipment.—The electronic equipment and recorder associated with the magnetometer is mounted in any convenient manner depending upon the available space and arrangement suitable for a given ship. It is

FIG. 14. Installation in Grumman "Goose."

powered from the regular 28-volt aircraft supply with some special attention given to the adjustment of the voltage regulators on the engine generators. The current consumption including the 100-watt converter for the recorder is about 15 amperes. When not limited by the aircraft load capacity, a separate 24-volt storage battery floated on the ship generators is desirable.

The installation in the experimental Grumman amphibian is shown in Figure

14. An additional auxiliary required is a bank of twenty 1.5-volt dry cells which supply the current for the compensator network used in nullifying a portion of the earth's field as already described. While the current in this compensating network may be standardized at will within the equivalent of 1 gamma, any drifts are troublesome and are to be eliminated if possible. Since the temperature coefficient of such batteries is relatively high, they are contained in a well-insulated, thermostatted box. This box also contains the Weston standard cell which serves as a standard for both the potentiometric circuit of the recorder and the compensating network. It also houses the 1½-volt working battery of the recorder potentiometer. The recorder is equipped so that its circuit is automatically standardized about every 30 minutes.

Standardizing Equipment—Helmholtz Coil.—The foregoing description of the magnetometer indicates that the calibration of the equipment is dependent ultimately upon the voltage of a standard cell and the permanency of resistance values in the compensating network, together with the field nullifying coil surrounding the element. Provision must be made for standardizing and occasionally checking the calibration of the entire equipment.

Figure 15 shows a Helmholtz coil which has been carefully constructed using

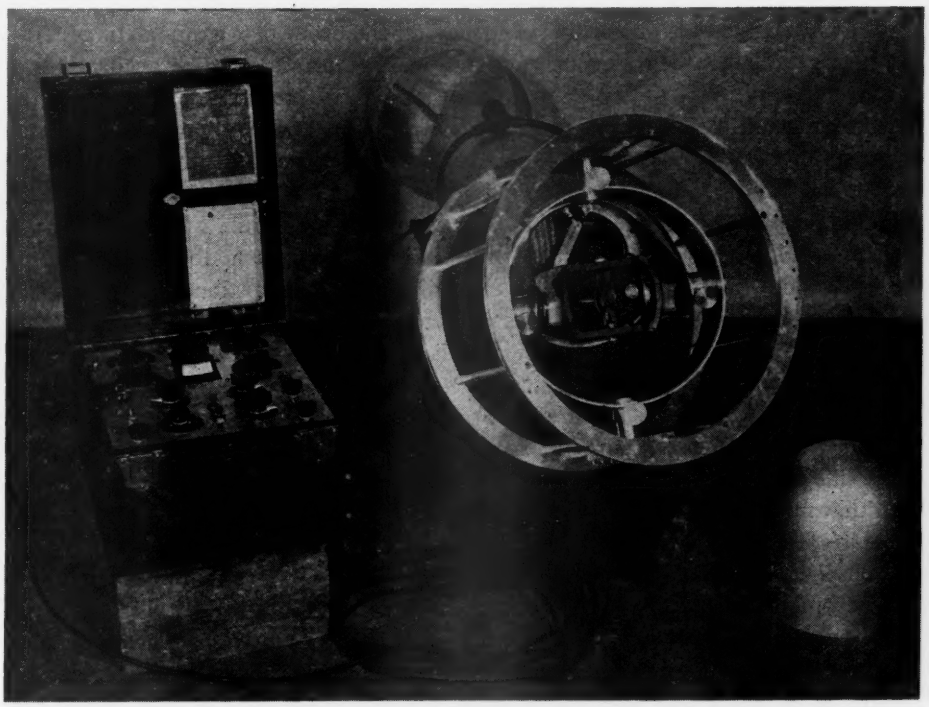

FIG. 15. Calibration Equipment—Helmholtz coil mounted on magnetometer unit.

aluminum throughout in order to maintain constancy of dimensions. Included is the control box containing a suitable resistance network together with a standard cell whereby known currents may be supplied to the Helmholtz coil to establish standard field strengths ranging from zero to some 80,000 gammas. The Helmholtz coil is mounted on gimbals and is provided with a ring base which fits the outer shell of the bird when the nose cap is removed. The magnetometer element is thus located at the center of the Helmholtz coil which may then be aligned parallel to the element and the gimbals locked. Known increments of the earth's field may thus be nullified and compared with the changes recorded by the magnetometer. This secondary standard Helmholtz coil and its associated current source is checked originally at the laboratory against a larger coil and equipment originally designed as an absolute magnetometer. The secondary standards agree within 0.25 percent or better.

In order that the magnetometer heads may be used interchangeably with any of the compensator panel units, all such units are standardized. The compensating coils on the magnetometer elements are then adjusted to match. As an example, a recent calibration check of two sets of compensators used interchangeably with two different birds gave agreement within 0.1 percent.

NAVIGATION AND POSITION DATA

We have aimed at a recording accuracy on the order of 1 gamma. In general, insofar as the instrument is concerned, the sensitivity and reading accuracy is of this order on the 300- or 600-gamma recorder ranges. However, even though the instrument may be capable of such operation, the actual attainment of the same accuracy on the final map involves some serious problems. Thus there remains the problem of handling diurnal variations of the earth's field itself and the even more difficult problem of correlating the observed intensity profile with ground position. For evidently where gradients are relatively large, a small error in position will introduce mapping errors far exceeding the observational errors of the magnetometer itself. These problems warrant brief consideration here.

If an airborne-magnetometer survey is to be divorced completely from the ground or ground crews, clearly, some type of very accurate navigation and ground-track recording is required. At present, no such navigation and recording equipment of requisite accuracy is available. Work is underway in an attempt to meet this problem, but, as yet, it is too early to hazard even a guess at the precision that might be attained.

Aerial Cameras.—If accurate airphoto reference maps of an area are available, the obvious solution is the use of a suitable aerial camera synchronized with the magnetometer record. By careful comparison of the flight strips with the aerial map, the ground track of the aircraft and hence the location of the magnetic profile may be plotted with considerable precision. However, in some areas of monotonous terrain, or over water, even this procedure may be difficult or perhaps impossible. Moreover, suitable aerial photo maps may not always be avail-

able though evidently in sectionalized country or inhabited and well-surveyed areas, the flight-strip photographs may be compared directly with the land map.

The airborne magnetometer will probably always be supplemented by an aerial camera which is operated continuously when flying a profile. The film may be synchronized with the magnetometer record either directly or by suitably identifiable fiducials. Currently, in Aero Service Corporation's and our operations, we are using strip-cameras producing a continuous strip film with suitable numbered fiducials introduced by an electrically operated shutter. The same fiducials appear on the magnetometer record as an instantaneous jog in the trace obtained by superposing a fraction of a millivolt signal on the recorded quantity. These fiducials are automatically injected at regular time intervals or at will by the flight director. Fiducials injected by the flight director are usually associated with definite land marks which aid in mapping. Evidently additional points are obtainable in the final mapping by interpolation between fiducials with due regard for any apparent changes in ground speed of the aircraft.

A similar technique is used by the Fairchild Aerial Surveys, Inc., except the strip camera is replaced by an intermittent type producing individual exposures with a reasonable overlap. This method appears to offer some advantages especially in the quality of the photograph secured and possibly certain other features. However, we cannot discuss the relative merits of the two methods in any detail here since we have not been able to procure a frame-by-frame camera for comparison.

In addition to the camera used for photographing the ground track of the aircraft, it may be convenient also to record the readings of several aircraft instruments. Such a camera, intermittently operated at the time fiducials are applied to the other recorders, photographs an array of instruments including compass, altimeter, airspeed, clock, and fiducial-number counter. The value of these records in the final plotting of data will be obvious.

Navigation.—The problem of navigating the aircraft on a preassigned and regular network of profiles with the desired accuracy will be appreciated only by those thoroughly familiar with flight technique. Over sectionalized or similar terrain evidently no serious problem arises. In other areas, exemplified by the extreme case of extensive waterwork, the problem of navigation on a regular grid of profiles with ordinary equipment ranges from difficult to wholly impossible. In fact, it may be said that herein lies the most difficult portion of airborne-magnetometer instrumentation if the flying of the profiles is to be done accurately and efficiently.

In some cases, it may be expedient to employ a ground crew to establish suitable markers to aid the pilot; lacking any airborne position indicator of sufficient accuracy, or landmarks to serve as guides, there is no alternative. Partial divorcement of the airborne operations from such ground crews may be obtained by the use of radio navigation aids. Today such devices are essential for extensive water areas.

Radio position indicators suitable for this work are limited at present to the R.C.A. Shoran system.[2] With an accuracy of some ±50 feet at any distance within operational range, the precision is adequate. However, at present this system operates in the 300- to 400-megacycle frequency band and thus has the line-of-sight limitations in range characteristic of these high frequencies even for an aircraft flying at 1,000–2,000 feet. Moreover, in jungle or similarly inaccessible areas, the problem of maintaining ground crews at the two Shoran ground stations may be serious. This merely emphasizes the need for self-sufficient airborne position-indicators.

In addition to the Shoran equipment, the Decca System* may eventually become available. It is a scheme somewhat similar to the Loran System (somewhat better known in the U.S.A.). In the Decca scheme a known triangular array of three transmitting stations sends out synchronized, r.-f. signals. The superposition or interference effects of these continuous wave transmissions then results in hyperbolic patterns or "lanes" covering the area. A phase comparison of the three r.-f. waves received at a given point permits identification of the receiver location on a suitably prepared chart of the "lanes" or interference pattern. The system operates in the 100–120 kc. region and hence is free from line-of-sight limitations. However, while the airborne receiver comprising the entire portable equipment is very compact, the ground-station equipment and particularly the low-frequency antenna system is quite bulky. The system also requires a ground-monitor receiving station in the network. The potential accuracy of the Decca system in contrast to present Loran is very high; certainly suitable for profile navigation.

The above-mentioned radio position indicators or developments of their general type appear to cover the radio methods which in the future might be useful for airborne magnetometric work. To obtain the maximum serviceability from such equipment, it will be necessary to devise suitable computors so that automatically during flight, a map of the plane's position may be plotted with sufficient accuracy for use as a final map. While such plotting devices are not available now, their use may be anticipated in the near future.

Coordination of Data.—While it is beyond the scope of this paper to enter into a detailed discussion of the interpretation technique or rather, the coordination of the field data required to produce the basic magnetic map, it is pertinent to illustrate the type of data secured by the airborne magnetometer.

Figures 16 and 17 are photographs of portions of the recorder chart showing the type of record secured by the experimental plane during initial commercial trials. The recorder was operating at a sensitivity of 500 gammas full scale, thus each small vertical division represents 5 gammas. Four typical fiducial markers are shown in Figure 16 which permit identification or correlation with the con-

[2] *Trans. Amer. Geoph. Union, 27* (1946), 459–463.

* The Decca Navigator Company, Ltd., 1–3, Briston Road, London S.W. 9, England.

tinuous aerial photographs taken simultaneously with the magnetic record. The small pedestal at the left portion of the trace is the automatic standardization of the recorder potentiometric circuit which occurs every 30 minutes. Figure 17 shows ten fiducials numbered in sequence and inserted as previously described by the flight director. An automatic 400-gamma step is also shown occurring when the presence of a strong negative anomaly carried the recording pen to the bottom of the scale. The sharp anomaly at fiducial No. 3233 is of interest as representing the disturbance caused by an igneous plug protruding at the surface. The time

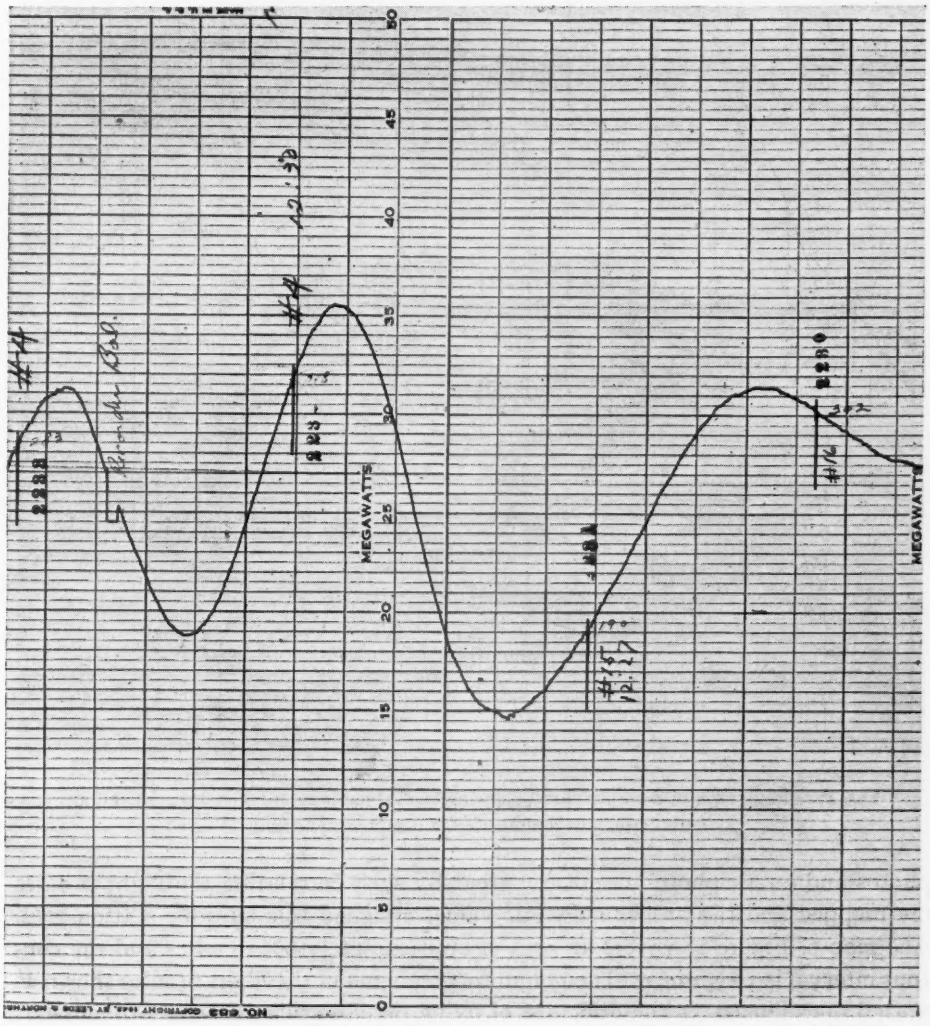

FIG. 16. Photograph of recorder chart. Operation at 500-gamma full-scale sensitivity and showing automatic balancing of recorder potentiometric circuit.

scale of these records is 1 in/min. (2 divisions on the horizontal scale) which at the flying speed maintained represents about 1.2 miles per horizontal division.

Figure 18 shows a portion of a magnetic map derived from data secured from the magnetometer recordings after careful correlation of the records and air

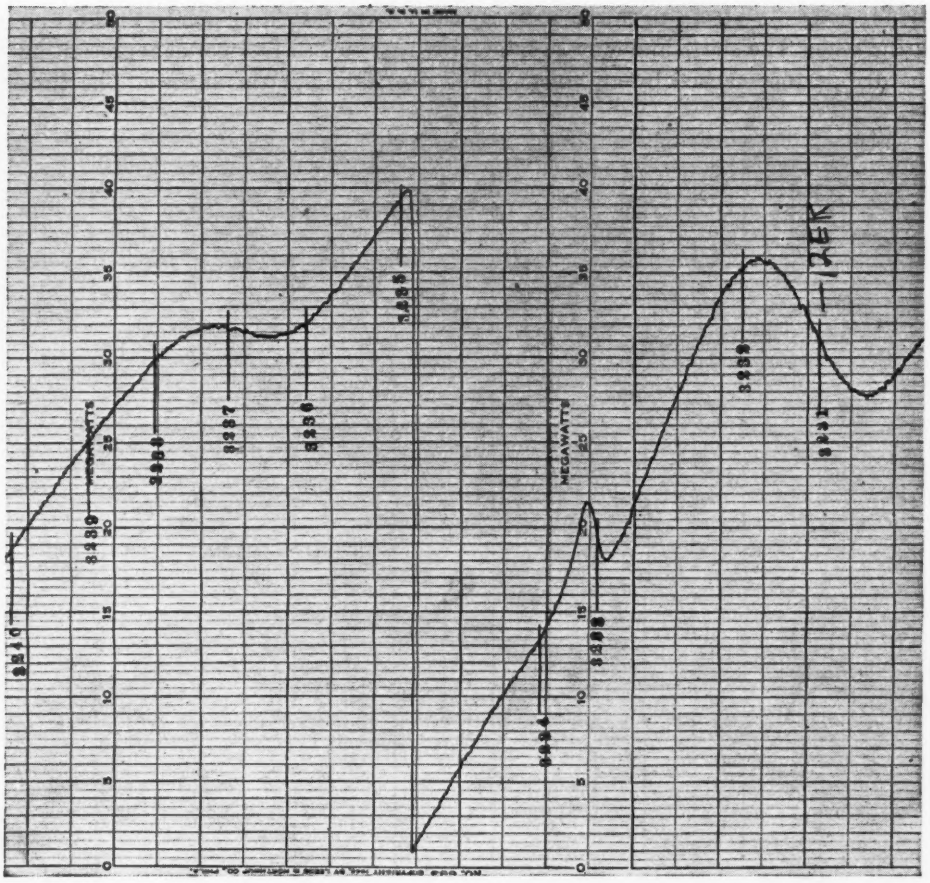

FIG. 17. Photograph of recorder chart, showing typical navigation fiducial marks and an automatic 500-gamma step in compensation field.

photos and an air-photo map of the area. By such correlation the flight profiles are mapped and the proper magnetic values assigned to a suitable station grid. The map of Figure 18 covers an area of approximately 8×18 miles and the contour interval is 10 gammas. The nonuniform spacing of the flight profiles shown as dotted lines illustrates the difficulty of flying precise grids over monotonous terrain without special navigation equipment. Moreover, it must be emphasized

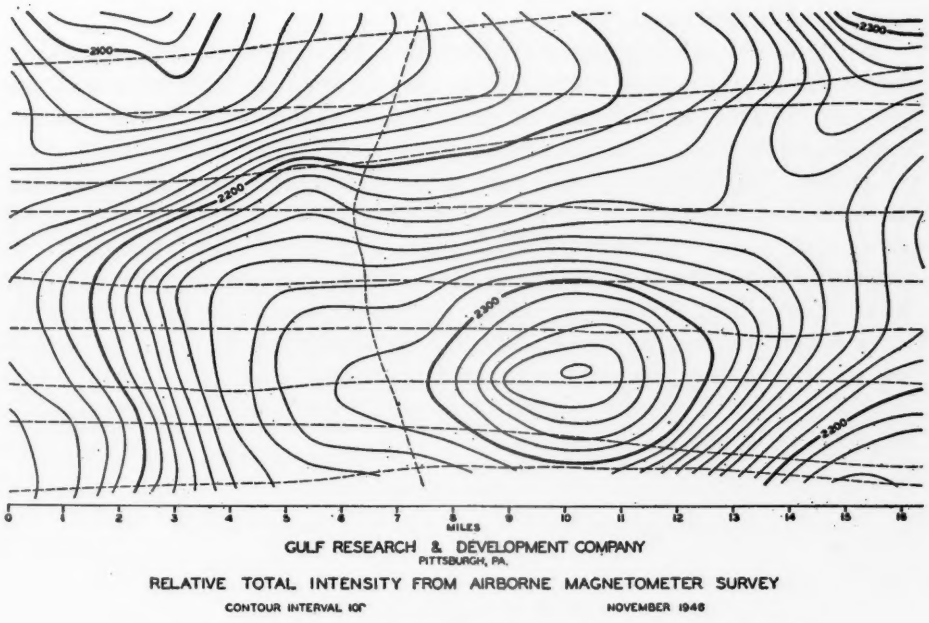

FIG. 18. Portion of typical magnetic map from airborne operations.

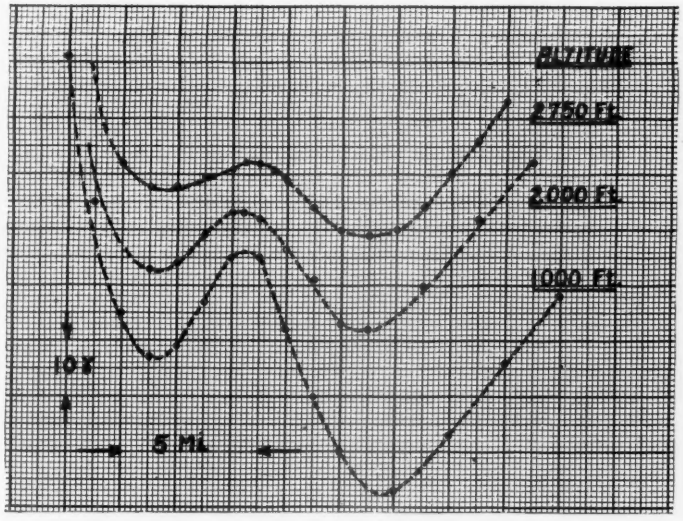

FIG. 19. Attenuation of shallow anomaly with increase in altitude of observation.

that this represents early semi-experimental work during which experience was only gradually developed.

While no attempt has been made here to outline the advantage of airborne magnetometric operations, the ability to map an anomaly from more than one elevation datum is of particular interest. Figure 19 shows the results obtained on profiles over a local anomaly when flown at 1,000, 2,000, and 2,750 feet above the ground. The observed profiles are plotted directly from the flight records at the vertical scale indicated. The relative magnitudes of the anomaly at the three observational levels are directly comparable, although for convenience in presenting the data, the absolute values at the three levels are not shown by the figure. It is evident that this technique, made available for the first time by airborne magnetometry, has clearly indicated the anomaly of Figure 19 to be shallow relative to the adjacent deep-seated disturbances of high intensity. This feature should prove to be of great usefulness in the detailed interpretation of magnetometric data.

A TOTAL FIELD MAGNETOMETER FOR MOBILE OPERATION*

EUGENE FROWE†

ABSTRACT

A magnetometer which measures the earth's total magnetic field is described. The detector or measuring element of the magnetometer contains three mutually perpendicular elements, two of which are utilized to orient the third, which in turn operates a recording device to record the total magnetic field. The detector elements are of the inductive type and do not require ferromagnetic material to give them the high sensitivity required in geophysical work.

The presence of a magnetic field in the region of the detector causes alternating currents to be generated in the detector elements. These currents are amplified to actuate motors which control the orienting and neutralizing functions of the magnetometer. A tape recorder gives continuous field readings. The accuracy of the magnetic data taken is better than five gammas.

It is the purpose of this paper to describe the theory of operation of a total-field magnetometer and to describe something of its operational characteristics. This magnetometer, for which patents have been applied, was developed in the laboratory of the Robert H. Ray Company, and, like some total-field magnetometers, it uses a three-element detector in which two elements are used to orient the third which in turn measures the total magnetic field. It is described as a mobile magnetometer because it is designed for use aboard ship as well as in the air. It has been operated aboard ship in the Gulf of Mexico, and it is believed that such service is economically feasible and offers advantages not obtainable from airborne operation.

In developing this magnetometer it was decided that the use of an earth-inductor-type detector would be desirable since it would eliminate the use of high permeability materials and give maximum stability to the signal output. The rotating-coil-type earth inductor (see Fig. 1) is not suitable as a magnetic-field detector since it is sensitive to any magnetic field in the plane perpendicular to the axis of rotation. The unwanted component of field must be aligned with the axis of rotation if other than total field operation is desired. Another disadvantage of the rotating-coil earth inductor is the contact noise at the slip rings which are used to take off the a.-c. voltage generated.

To eliminate the necessity for orientation and to produce a device which measures a magnetic field with vector properties, a vibrating-coil magnetometer was developed. Figure 2 illustrates the basic principle involved. The belt in the center foreground drives a pulley, which is connected to a crankshaft. The crankshaft operates the connecting rod, causing the coil to oscillate. With proper design of the cam and connecting links, the coil will execute a sinusoidal vibratory motion and if the conductors cut magnetic lines of force an a.-c. voltage will be generated. Note that in this motion the conductors move in a horizontal plane

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only and will generate an a.-c. voltage only if there is a vertical magnetic field. If there is a horizontal component of field, the vibrating coil will not detect it regardless of its direction. This coil, then, will detect magnetic fields along only one line; i.e., the vertical line. Note that because this is a vibrating coil, a pair of flexible leads may be used instead of slip rings for taking off the the voltage gen-

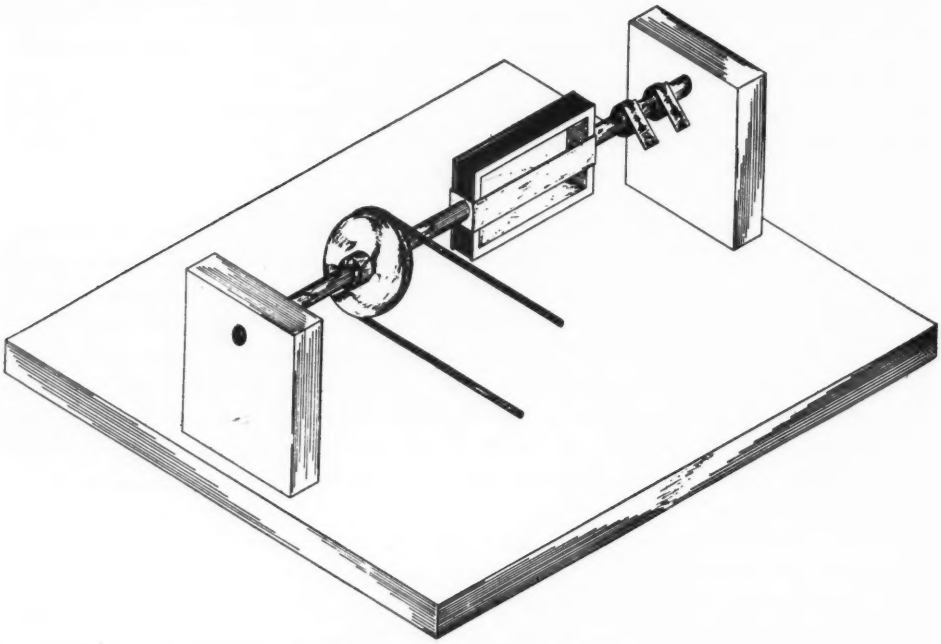

FIG. 1. Rotating-coil earth inductor.

erated. The elimination of slip rings is a distinct advantage since high-speed sliding contacts are a source of noise in a sensitive device of this type. Unless the angle of vibration is very small, the conductor cutting the magnetic lines of force will actually have a small vertical motion. Because of this vertical motion, a magnetic field in a horizontal plane and perpendicular to the shaft will be cut and an a.-c. voltage will be generated. This a.-c. voltage, however, will have a frequency twice that of the horizontally generated voltage and may easily be eliminated by a suitable filter network in the amplifier or by neutralization of the magnetic field. Both methods are used in this magnetometer to eliminate this second harmonic.

Figure 3 shows further development of the vibrating coil magnetometer. A pair of rectangular field coils are constructed around the vibrating coil in such a way that the magnetic field measured by the magnetometer may be neutralized. By passing direct current through these coils the magnetic field in the region of the vibrating coil can be reduced to zero, and when this condition is reached, a

sensitive a.-c. voltmeter attached to the flexible leads of the vibrating coil will indicate zero. By measuring the direct current required to attain this condition, the magnetic field can be accurately determined. Such an arrangement is satisfactory as a manually operated magnetometer and nothing more is required for measuring one component of field. If the operator in making a reading observes

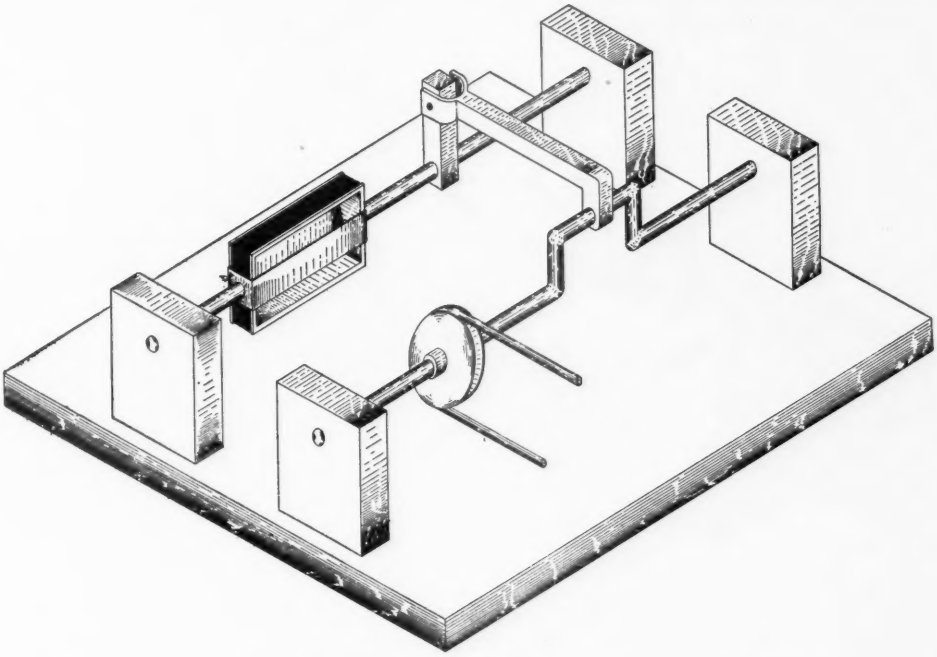

FIG. 2. Vibrating-coil earth inductor.

a voltage on the voltmeter, he can adjust the current until a null condition is attained. For the automatic current adjustment, however, a reference voltage of the proper phase relationship is needed to give sense to the adjustment. To give us such a reference voltage, a smaller vibrating coil has been added to the shaft of the main vibrating coil. How this coil functions can be seen qualitatively by this explanation: If the neutralizing current is too little, the field around the two coils will be in the same direction and the voltages generated will be in phase; if the neutralizing current is too large, the field around the main vibrating coil will be reversed and the voltages of the two vibrating coils will be 180 degrees out of phase. Notice that this auxiliary coil is not included within the pair of neutralizing coils. The voltages of these coils with suitable electronic mixing equipment can be utilized to control a small motor with a rheostat attached to its shaft to keep the magnetic field automatically neutralized.

To obtain the best results from a magnetometer survey it is desirable to attain an accuracy of the order of several gammas. If the vertical component of

field were to be measured to this accuracy, alignment must be maintained to a few seconds of arc. Such precision would be extremely difficult in a moving aircraft or ship. If the total magnetic field were measured, a misalignment of ½ degree could be tolerated with a resulting error of only 3 or 4 gammas and for this reason the three-element-type total field magnetometer was constructed.

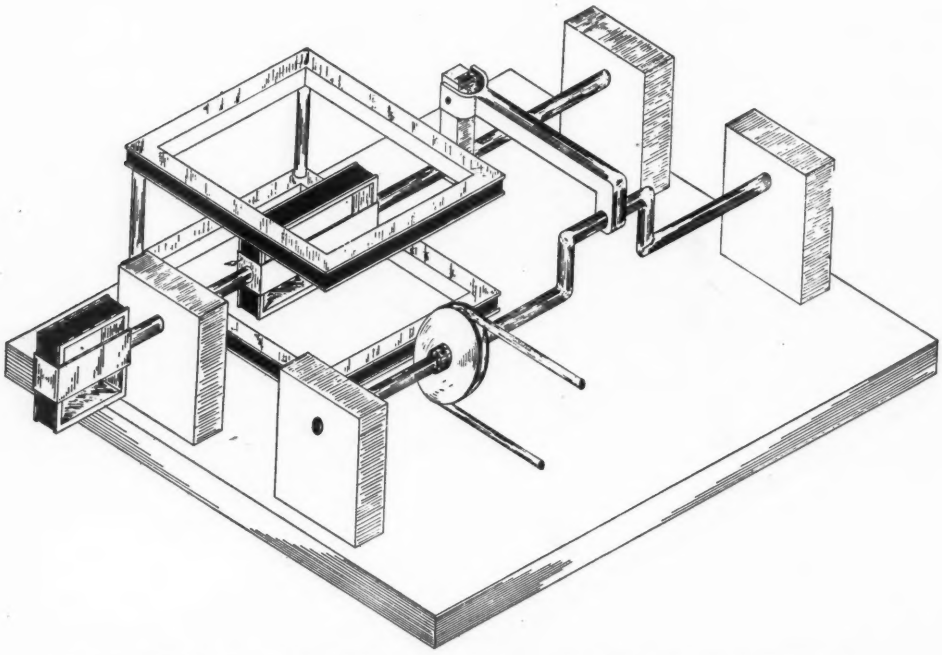

FIG. 3. Vibrating-coil earth inductor with neutralizing field and reference voltage coils.

Figure 4 is a schematic drawing of the complete magnetometer. The vibrating coils are mounted on a framework in such a way that they measure magnetic fields mutually perpendicular to each other. The framework is mounted on gimbals so that the total-field coil can be oriented in any direction. An a.-c. motor, not shown, supplies power to make the vibrating coils operate. The top and bottom vibrating coils are connected through amplifiers and mixers to the motors which keep the system aligned with the earth's magnetic field. If a misalignment should occur, the voltage generated in the top and bottom coils will cause the orienting motors to operate in such a direction as to realign the system and thus the total-field coil vector is maintained in alignment with the earth's magnetic field. Most of the earth's magnetic field is neutralized with the inner pair of field coils, and a potentiometer and a shunt are used to measure the current required. The remainder of the field is neutralized with the outer pair of field coils. If an unbalance occurs, the a.-c. voltage generated in the total-field coil causes the motor connected to a rheostat to adjust the current and balance the magnetic field.

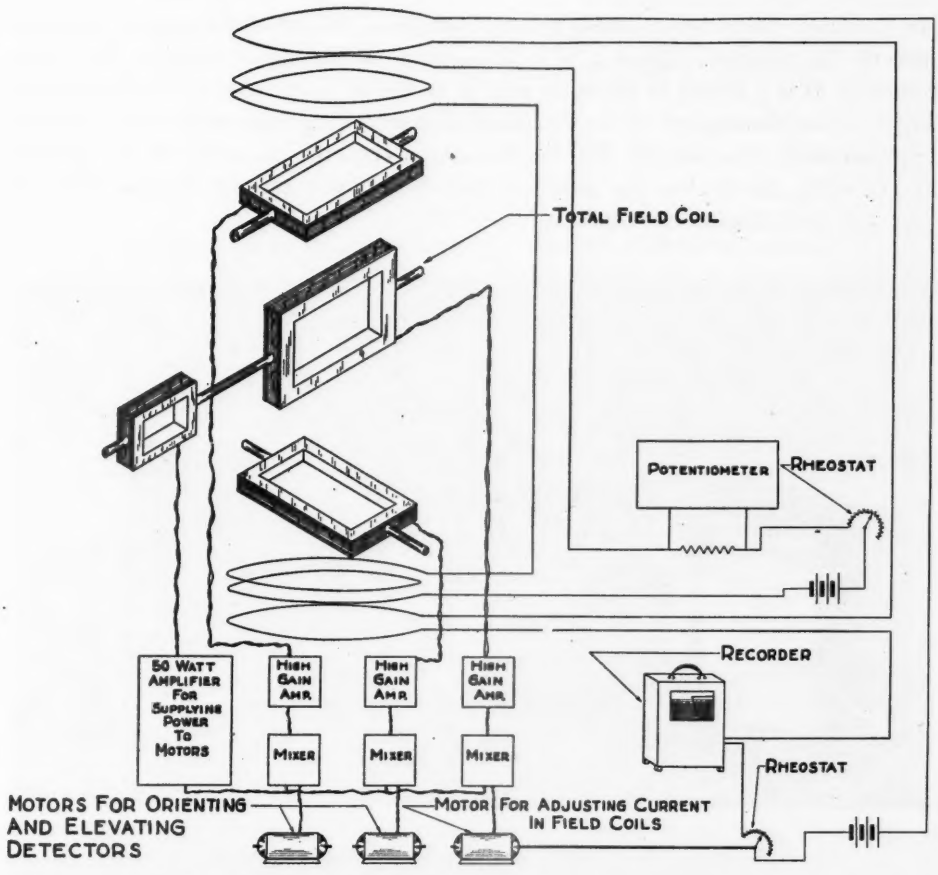

FIG. 4. Schematic drawing of the vibrating-coil magnetometer.

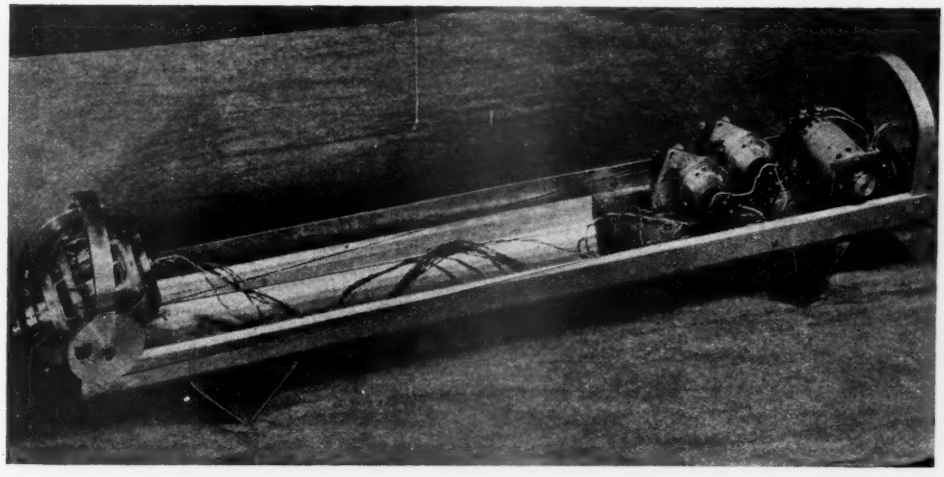

FIG. 5. Magnetometer detector with cover removed.

An Esterline-Angus ink recorder gives a continuous record of the current changes directly in gammas. Figure 5 is a photograph of the detector with the cover removed. It is 7 inches in diameter and 38 inches in length and weighs 9 pounds. Figure 6 is a photograph of the electronic and recording equipment which weighs approximately 150 pounds. The magnetometer requires 350 watts of a.-c. power at 115 volts, 400 cycles. For airborne operation power may be derived from an inverter operating on 24 volts d.c.

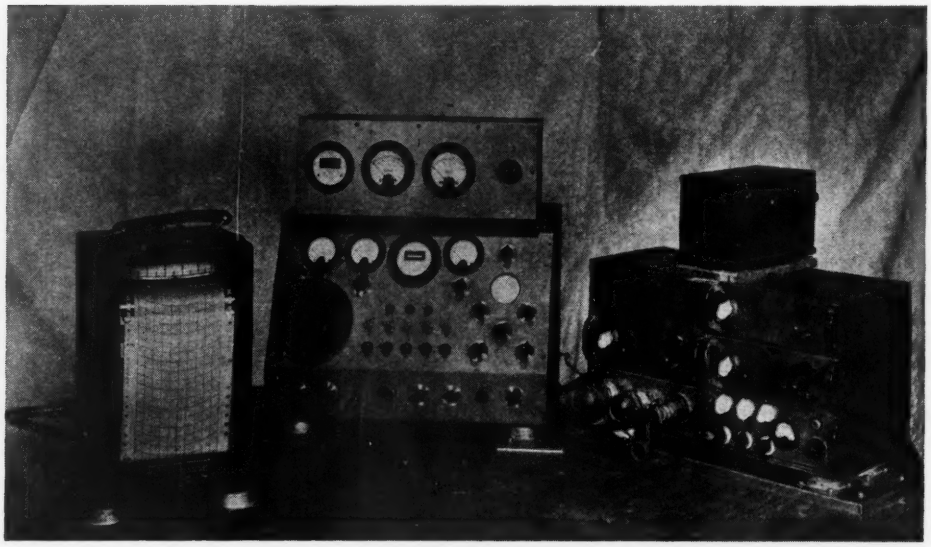

FIG. 6. Magnetometer amplifier and recording equipment.

A test was run with this magnetometer recently aboard ship in the Gulf of Mexico. To minimize the magnetic effect of the ship, a detector was mounted on a boom extending 15 feet forward of the ship. The area run was over a known shallow salt dome, and an anomaly of 25 gammas was observed. Shipborne magnetometer surveys, while slower than airborne surveys, give greater detail to the anomaly under investigation.

A LINE-INTEGRAL METHOD OF COMPUTING THE GRAVIMETRIC EFFECTS OF TWO-DIMENSIONAL MASSES*

M. KING HUBBERT†

ABSTRACT

Many computing schemes have been devised for determining the gravity anomalies produced by two-dimensional masses. Most of these are based upon the evaluation of an areal integral and require specially constructed templates or tables. In the present paper it is shown that the gravity anomaly Δg at the origin of coordinates, produced by a two-dimensional mass of constant density contrast $\Delta\rho$, may be obtained quite simply by means of either of the line integrals

$$\Delta g = 2k\Delta\rho \oint \theta dz = -2k\Delta\rho \oint z d\theta,$$

where z is the vertical coordinate, and θ the polar coordinate expressed in radians of a point on the periphery of the mass in a plane normal to its axis and passing through the origin

The line integrals are evaluated around the periphery of the mass and are of opposite sign if taken in the same direction of traverse, or are of the same sign if taken in opposite directions.

For use of these integrals no special equipment is required other than a simple template consisting of radial lines, θ=const., and horizontal lines, z=const., which can be constructed in a few minutes with protractor and scale. This can be constructed either for 1:1 or for an exaggerated vertical-to-horizontal scale.

A mass distribution is said to be two-dimensional when its density varies as the same function of position on each of a family of parallel planes. If one of these planes is chosen as the xz-plane in a system of cartesian coordinates, then the density would be an arbitrary function of x and z, but would be constant along any line parallel to the y-axis. The computation of the gravitational effects of such distributions is much simpler than for three-dimensional distributions, since in the former case the integration is limited to a plane, whereas in the latter case it must be performed over a volume of space.

Computations of the effects of two-dimensional masses are of considerable interest in gravimetric prospecting because many of the most common of geologic structures—folding parallel to a given horizontal axis, parallel faulting, ridge-and-valley topography resulting from the erosion of folded structures, etc.,—can be approximated by such distributions.

Many computing schemes for the effects produced by two-dimensional masses have been described in the literature. Mostly these require the use of special templates, mechanical devices, or tables of functions. Moreover, they usually are not applicable to masses extending to infinity or lying too near the horizon of the station, consequently, the existing methods are often not well suited to computing problems encountered in practice where the masses often do extend to infinity, and, in such problems as terrain connections, also lie near the horizon. A

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need has therefore been felt for a simpler and more versatile method of making such calculations, which has satisfactorily been met by the method described below.

THE PRINCIPLE OF THE METHOD

Attraction of Plane Lamina.—In order to understand the principle of the method, let us choose a coordinate system with the xz-plane as the plane of integration and with the y-axis horizontal and parallel to the strike or axis of the mass configuration. Let the x-axis be horizontal and the z-axis vertical and positive downward. Let the origin be taken as the point at which the gravitational effect of the body will be computed. Since this attraction will be detected by a gravity meter only as an increment Δg to the total earth gravity g, only the z-component of the attraction need be considered and it is this which we seek to compute.

First consider an infinite horizontal plane lamina bounded by the planes z, and $z+dz$ (Fig. 1). Let dS be an element of area of this plane in three-dimensional

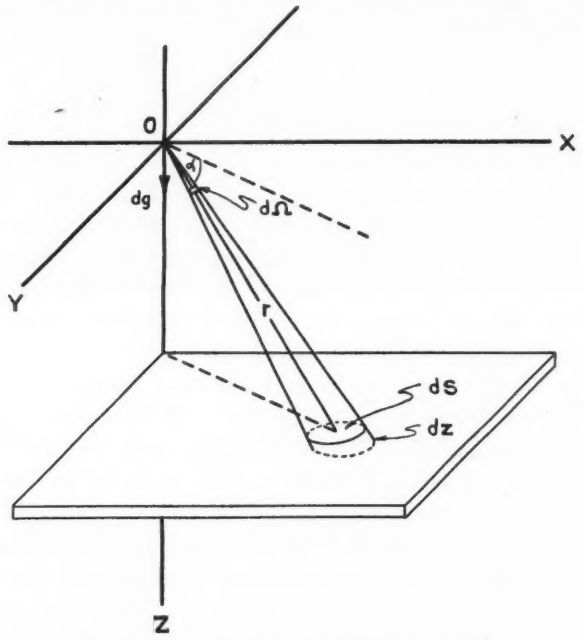

FIG. 1. Attraction of infinite plane lamina.

space and let ρ be the volume density of the element. The vertical component, at the origin, of the attraction due to this element will be

$$dg = \frac{kdm}{r^2} \sin \alpha = \frac{k\rho dz dS}{r^2} \sin \alpha, \qquad (1)$$

where k is the constant of gravitation, r the polar distance of the element from

the origin, and α the angle of depression of r from the horizon of the station.

But

$$\frac{dS \sin \alpha}{r^2} = d\Omega \tag{2}$$

is the solid angle subtended at the origin by the area dS, so that equation (1) can be written more simply in the form:

$$dg = k\rho dz d\Omega. \tag{3}$$

If we now consider a finite area S of arbitrary shape the attraction at the origin due to the enclosed mass will be

$$g = kdz \int_S \rho d\Omega, \tag{4}$$

and if ρ is constant over S, this simplifies to

$$g = k\rho\Omega dz. \tag{5}$$

Likewise, for a given solid angle Ω, the attraction of the matter enclosed between two horizontal planes z_1 and z_2 will be obtained by integrating equation (5) with respect to z:

$$g = k\Omega \int_{z_1}^{z_2} \rho dz, \tag{6}$$

and again if ρ is constant this becomes,

$$g = k\rho\Omega(z_2 - z_1), \tag{7}$$

which is the contribution to gravity at the origin of the mass contained in the frustrum of a slant cone with vertex at the origin.

Attraction of $d\theta dz$-Solenoid.—Let us next consider the attraction at the origin which will result if we let the element of surface area dS become a narrow linear strip of infinite length parallel to the y-axis. Such a strip will be defined by the area on the plane z=const. lying between two inclined planes which intersect on the y-axis and make with the x-axis angles of θ, and $\theta+d\theta$, respectively (Fig. 2).

As we have seen from equation (5), the attraction of this strip will be proportional to the solid angle subtended by it at the origin. The solid angle $d\Omega$ between two planes intersecting at an angle $d\theta$ will bear the same ratio to the total solid angle which the plane angle $d\theta$ bears to the total plane angle. The total solid angle is the ratio of the surface area of a sphere to the square of its radius, or 4π, and the total plane angle is 2π. Thus

$$\frac{d\Omega}{4\pi} = \frac{d\theta}{2\pi},$$

or

$$d\Omega = 2d\theta. \tag{8}$$

Introducing this into equation (3) then gives for the attraction of such a strip

$$dg = 2k\rho d\theta dz, \tag{9}$$

which we shall regard as the fundamental differential equation of the attraction of a two-dimensional mass. The intersection of the two planes θ and $\theta+d\theta$ with

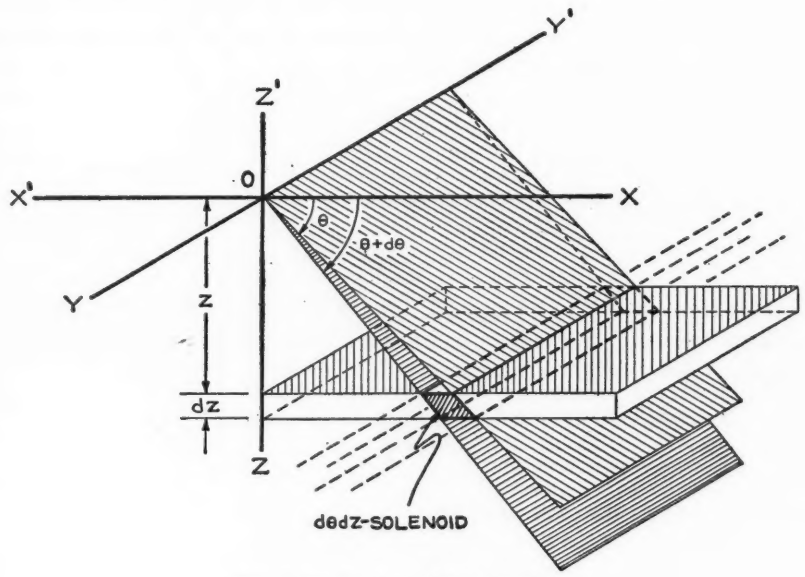

FIG. 2. Illustration of $d\theta dz$-solenoid.

the planes z and $z+dz$ defines an elementary prism or solenoid of infinite length and, in terms of the variables θ and z, of cross section $d\theta dz$. This we shall call the $d\theta dz$-solenoid.

For a finite area in the plane of integration

$$g = 2k \iint \rho d\theta dz, \tag{10}$$

and when ρ is constant over the area

$$g = 2k\rho(\theta_2 - \theta_1)(z_2 - z_1), \tag{11}$$

independently of the absolute magnitudes of either θ or z.

Areal Integration by Means of $\Delta\theta\Delta z$-solenoids.—Equations (9) and (11) afford at once a simple basis for the computations of the gravimetric effects of two-dimensional masses. The coordinates θ and z are taken as the variables of integra-

tion, and the plane of integration is divided by radial lines from the origin, $\theta = \text{const.}$ with constant spacing $\Delta\theta$, and by horizontal lines $z = \text{const.}$ with constant spacing Δz, into a mosaic of $\Delta\theta\Delta z$-solenoids.

If the solenoids are chosen small enough that ρ may be considered constant for each (Fig. 3) the contribution to gravity of a single solenoid will be:

$$\Delta g = 2k\rho\Delta\theta\Delta z, \tag{12}$$

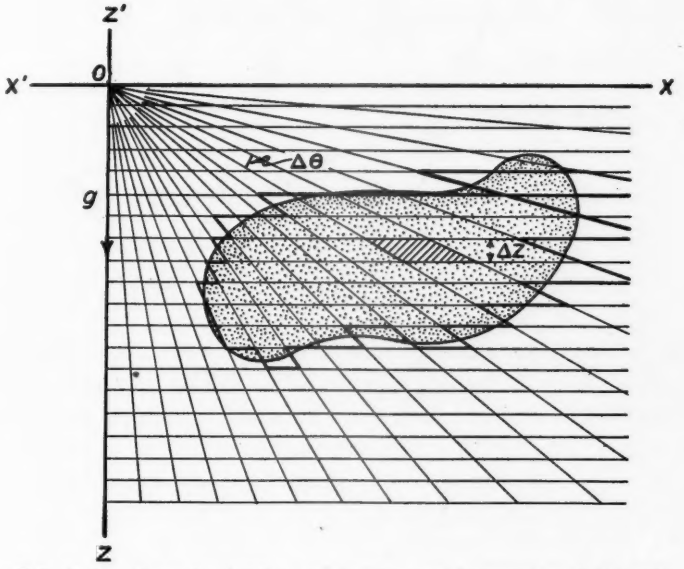

FIG. 3. Calculation of gravitational attraction by areal integration of $d\theta dz$-solenoids.

and the integration over any area will be approximated by

$$g = 2k\sum_{i=1}^{i=n} \rho_i\Delta\theta\Delta z, \tag{13}$$

or, if ρ is constant over the whole area of integration,

$$g = 2k\rho\sum \Delta\theta\Delta z = 2k\rho n\Delta\theta\Delta z, \tag{14}$$

where n is the number of solenoids within the area.

This constitutes a very simple method of computing the effects of two-dimensional masses so long as the area of integration is finite in extent and not too near the horizon. Like most areal integrations, however, it breaks down when these conditions are not satisfied, yet despite this handicap the method is still valuable in that it gives the computer a simple picture of masses having equal gravimetric effects at the station despite variation in size and shape, since for the same density the contribution of each unit solenoid is the same.

Line-integral Method of Integration.—The method just described represents

an *areal* integration over the area of cross section of the mass. To avoid some of the difficulties inherent in it, let us now consider the corresponding *linear* integrations around the periphery of the area. Around an elementary solenoid $d\theta dz$ (Fig. 4) bounded by the lines θ and $\theta+d\theta$, and z and $z+dz$, consider the line integral $\oint \theta dz$.

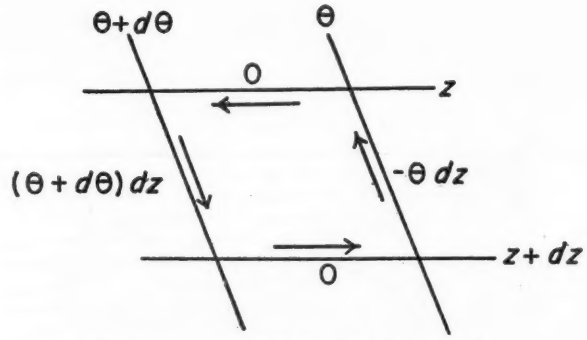

FIG. 4. Line integral about a $d\theta dz$-solenoid.

Starting at the intersection of the lines θ and z, we traverse the circuit in the sense z, $\theta+d\theta$, $z+dz$, θ. In making this circuit dz will be zero on two sides and the resulting integral will be:

$$\oint \theta dz = 0 + (\theta + d\theta)dz + 0 - \theta dz$$

$$= d\theta dz. \tag{15}$$

Traversing the circuit in the opposite direction gives the same result but with a negative sign.

Alternatively, consider the integral $\oint z d\theta$, where the circuit this time is traversed in the sense θ, $z+dz$, $\theta+d\theta$, z.

$$\oint z d\theta = 0 + (z + dz)d\theta + 0 - z d\theta$$

$$= + dz d\theta. \tag{16}$$

Traversing the circuit in the opposite sense again changes the sign.

Over a finite area S we may obtain the $\iint d\theta dz$ by performing either of the line integrals of equations (15) or (16), and then integrating the results over the area. Thus

$$\iint_S d\theta dz = \iint_S \left[\oint \theta dz\right] = \iint_S \left[\oint z d\theta\right], \tag{17}$$

where the respective line integrals are taken in a positive sense. But as will be seen from Figure 5, when a separate line integral is taken around each of the ele-

mentary solenoids of the area, each interior path is traversed twice, once in each direction, whereas the exterior paths are traversed but once, and always in the

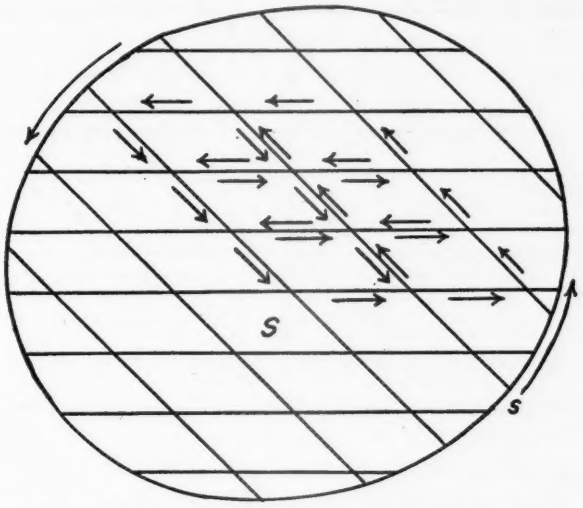

FIG. 5. Conversion of surface integral to line integral.

same sense. Hence, the integrals on all interior paths cancel one another while all those on the exterior paths are cumulative and of like sign. Consequently

$$\iint_S d\theta dz = \oint_s \theta dz = \oint_s z d\theta, \tag{18}$$

where the respective line integrals are each taken in its positive sense around the exterior periphery of the area of integration.

By combining equations (10) and (18) the gravimetric effect of a finite mass of constant density is thus obtainable by either of the integrals:

$$g = 2k\rho \oint \theta dz = 2k\rho \oint z d\theta, \tag{19}$$

taken in the appropriate sense.

Illustrative Example.—To illustrate how the method works let us compute the attraction of the mass bounded by the planes z_1 and z_2 (Fig. 6). Employing the form

$$g = 2k\rho \oint \theta dz,$$

we circumscribe the mass by traversing the surface z_1 from $x = +\infty$ to $x = -\infty$, then descend to the z_2-surface which is traversed from $x = -\infty$ to $x = +\infty$, finally closing the circuit by returning to the z_1-surface at $x = +\infty$.

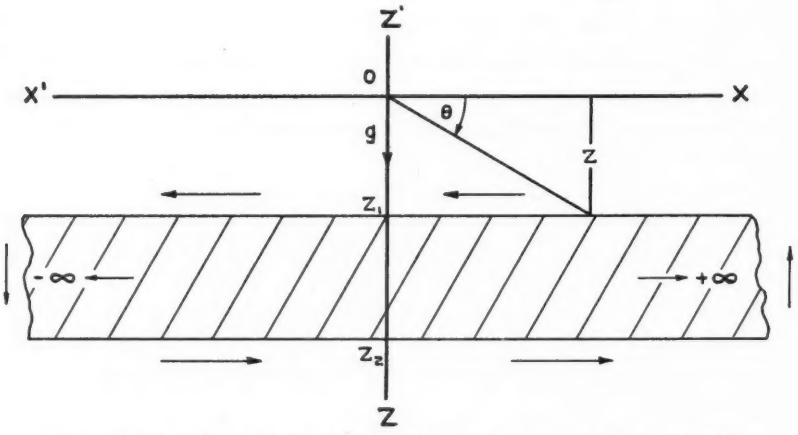

FIG. 6. Calculation of attraction of infinite plate by means of line integrals.

For these four sections of the traverse we have the sum of the four partial integrals:

$$g = 2k\rho\left[\int_{x=+\infty, z=z_1}^{x=-\infty} \theta dz + \int_{z_1, x=-\infty}^{z_2} \theta dz + \int_{x=-\infty, z=z_2}^{x=+\infty} \theta dz + \int_{z_2, x=+\infty}^{z_1} \theta dz\right]. \quad (20)$$

The first and third integrals vanish since $dz=0$, and the fourth vanishes because $\theta=0$. This leaves only the second integral for which θ assumes the constant value π. Consequently equation (20) reduces by inspection to the familiar result:

$$g = 2\pi k\rho \int_{z_1}^{z_2} dz = 2\pi k\rho(z_2 - z_1).$$

Let us now solve the same problem by means of the equation

$$g = 2k\rho \oint z d\theta.$$

In this case we begin at the point $(x=+\infty, z=z_1)$ but traverse the circuit in the opposite direction. For the four sections of the path we find

$$g = 2k\rho\left[\int_{z_1, x=-\infty}^{z_2} z d\theta + \int_{x=+\infty\ z=z_2}^{x=-\infty} z d\theta + \int_{z_2, x=-\infty}^{z_1} z d\theta + \int_{x=-\infty, z=z_1}^{x=+\infty} z d\theta\right]. \quad (21)$$

In this case the first and third integrals vanish because $d\theta=0$, and the integrands of the second and fourth integrals assume the constant values, respectively, of z_2 and z_1. Hence, the equation reduces to

$$g = 2k\rho\left[z_2 \int_{x=+\infty}^{x=-\infty} d\theta + z_1 \int_{x=-\infty}^{x=+\infty} d\theta\right]$$
$$= 2k\rho(\pi z_2 - \pi z_1) = 2\pi k\rho(z_2 - z_1).$$

Graphical Evaluation of Line Integrals.—It is thus seen that for any path along which either θ or z is constant the integrals can be evaluated by inspection. In general, however, this special condition is not satisfied, and the paths along which the integrations are to be performed are not capable of simple analytical expression. In these cases the integrals must be evaluated approximately by some form of graphical and numerical calculation. Thus the integrals (19) can be approximated by the summations

$$\left.\begin{aligned} g &= 2k\rho \sum \theta \Delta z, \\ g &= 2k\rho \sum z \Delta\theta. \end{aligned}\right\} \tag{22}$$

By taking constant increments Δz or $\Delta\theta$, these equations simplify to

$$\left.\begin{aligned} g &= 2k\rho \Delta z \sum \theta, \\ g &= 2k\rho \Delta\theta \sum z, \end{aligned}\right\} \tag{23}$$

so that their evaluation consists in determining the value of the integrand (θ or z) for each increment Δz or $\Delta\theta$ around the periphery of the figure, and adding the results, the signs being respectively positive or negative as the increment (Δz or $\Delta\theta$) increases or decreases.

The principle of such a graphical evaluation is illustrated in Figures 7 and 8. The performance of the integration is facilitated if there is superposed upon the figure to be integrated a network of lines $\theta = \text{const.}$, $z = \text{const.}$ at constant spacing $\Delta\theta$ and Δz, respectively. From this, for each increment of the variable of integration around the periphery of the figure, the value of the integrand can be read off graphically.

Such an integration is also invariant with respect to distortion as may be seen by imagining the θz-network, as well as the figure to be integrated, to be drawn upon a sheet of thin rubber. Integrations performed before and after giving this sheet an arbitrary distortion would still give the same results since the measuring device is deformed in the same manner as the thing to be measured.

This fact is useful in many geological calculations where the horizontal distances are commonly of the order of 10-fold, or more, times the vertical distances. In such cases it is often convenient to draw cross sections with a large vertical exaggeration. The foregoing integrations are still valid for such cases provided the θz-diagram is drawn with the same vertical exaggeration.

Each of equations (24) consists of two essential factors, the constant $2k\rho$ and the purely geometrical factor $\Delta z \sum\theta$, or $\Delta\theta \sum z$. It is only the latter which is involved in performing an integration. Of the two geometrical components, the angle θ is dimensionless, and z has the dimensions of length. It is convenient, therefore, in making calculations to draw the lines z-constant directly upon the cross section to be integrated and with a spacing in accordance with the vertical scale of the cross section. This eliminates completely any further consideration of the scale of the drawing.

Suppose, for example, that 10 meters has been chosen as the interval for Δz. All that is necessary then is to space the lines, $z=$const., 10 meters apart in accordance with the vertical scale of the drawing.

This leaves only the radial lines, $\theta=$const., to be accounted for. Since it is often desirable to make computations at successive points along a profile it is convenient to draw the radial lines, $\theta=$const., on a transparent template. Since

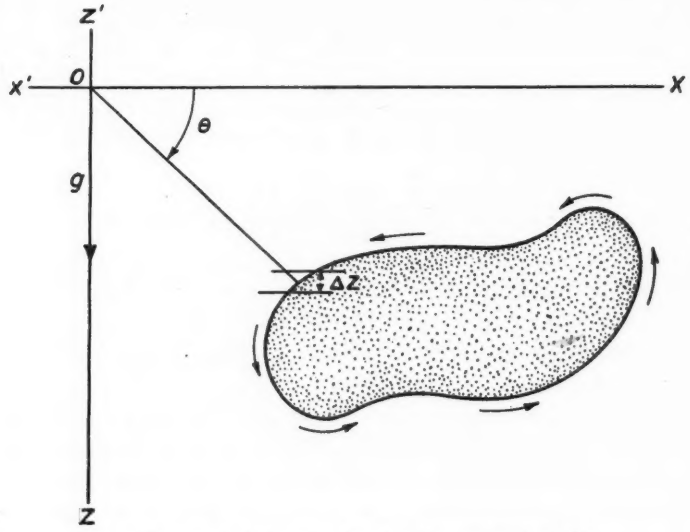

FIG. 7. Geometrical elements involved in evaluating $\int \theta dz$.

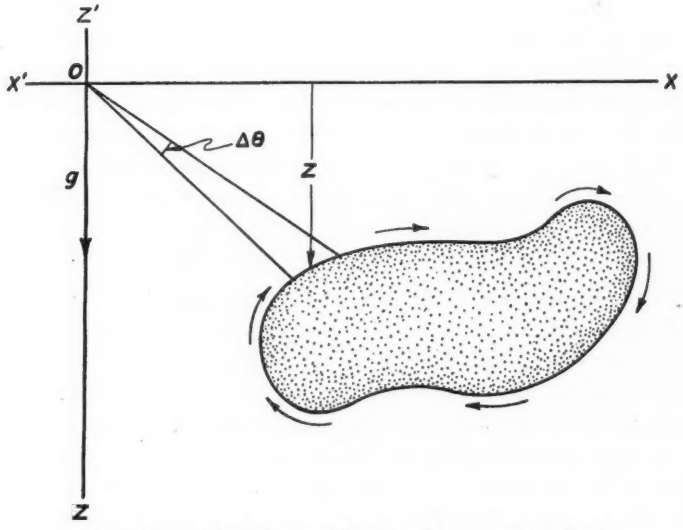

FIG. 8. Geometrical elements involved in evaluating $\int z d\theta$.

θ is dimensionless such a template will be equally applicable to any cross section of whatever scale provided only that the template has the same vertical exaggeration as the cross section. In practice only a few different vertical distortions are commonly employed, such as, say, 1:1, 1:5, 1:10, etc. Angle templates for each of these can be constructed, and when the proper one of these is placed over the cross section containing both the figure to be integrated and the lines, $z=$ const., nothing more remains to be done except to read off the numbers and talley the results.

Either an areal or a linear integration may be employed, depending upon the nature of the figure.

Optimum Size of $\Delta\theta\Delta z$*—Solenoid.*—A final word may be said about the optimum size for a $\Delta\theta\Delta z$-solenoid. This may well vary with the nature of the problem. One useful choice might be of a unit solenoid which would produce an increment of gravity of 0.01 milligal (10^{-5} gal) when filled with a material whose density is 1 gm/cm^3. Solving equation (12) with these numerical data gives

$$\Delta\theta\Delta z = \frac{\Delta g}{2k\rho} = \frac{10^{-5}}{2 \times 6.67 \times 10^{-8}} = 75.0 \text{ cm.}$$

Thus if $\Delta\theta$ were 1 radian, z would be 75 cm.; if it were 0.1 radian, Δz would be 7.5 meters, etc.

A convenient interval for $\Delta\theta$ would appear to be about 0.05 radians (ca. 2.5°) for which Δz would be 15 meters (45.8 ft.), which should suffice for many geological calculations. In general, however, the choice of the optimum size for the $\Delta\theta\Delta z$-solenoid would depend upon the problem under consideration and should be made to suit one's individual needs.

GRAVITATIONAL TERRAIN EFFECTS OF TWO-DIMENSIONAL TOPOGRAPHIC FEATURES*

M. KING HUBBERT†

ABSTRACT

If terrain corrections are not systematically made when conducting gravity surveys, it is a matter of some importance to locate stations away from points for which this effect is a maximum. While this fact is fully appreciated, our literature is deficient in information that a field man could use telling him how large would be the effect of a given topographic feature, or how far away the station should be placed to keep the error within prescribed limits.

To meet this need continuous profiles of terrain effects across 47 different forms of two-dimensional topography have been computed and are presented herewith. These are expressed dimensionlessly so that each figure represents an infinite class of features having the same shape. In addition, the profile for each ridge is also valid for valleys of the same form, but inverted. The data thus are applicable to a double infinity of cases.

These profiles are also useful to the interpretive staff for determining quickly whether certain small anomalies are significant, or whether they are more probably the result of local uncorrected terrain.

In making gravity surveys, if the inherent precision of modern gravity meters —a precision approaching 0.01 milligal—is to be fully utilized it would be necessary to make systematic computations of the effect of the local terrain about each station, and to apply the result as a correction to each gravity measurement. Not only are such calculations laborious but the required topographic maps often do not exist, so that essential topography would have to be provided by the survey crews.

In view of these difficulties such terrain corrections are usually not made, and it then becomes a matter of particular importance for the field crews to know how to choose station locations at points which will minimize the terrain error, or at least to avoid choosing locations where the terrain effect is near maximum. It is also important for the gravity interpretive staffs to have some knowledge of the approximate magnitude of the errors that may result from the neglect of terrain corrections in various kinds of topography, so that proper allowance can be made for such possible errors.

Although the nature of the terrain effect has long been known, and has been extensively discussed particularly in geodetic literature, it still is not as well known as it should be among the operating staffs of gravity parties. Moreover, our literature is particularly deficient in concrete examples of computations of this effect for specific types of topographic features, to which either a field man or an interpretor could refer on short notice.

In response to a demand for this kind of information on the part of the per-

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sonnel and contract crews of the Shell Oil Company, a series of profiles of terrain corrections across an extensive variety of two-dimensional topographic forms has been prepared. It is thought these may be of sufficient interest and use to the industry at large to justify their publication.

NATURE OF THE TERRAIN EFFECT

The terrain effect at a given gravity station may be defined as the difference between the value of gravity that would exist at that station if the topography were a level surface with the same elevation as the station, and the value that actually is observed. Stated in another manner, it is the change that would be produced in the observed value of gravity at a given station if the existing topography were leveled off to the elevation of the station, all masses above this level being removed and all voids below being filled with rock of average local density, as shown in Figure 1.

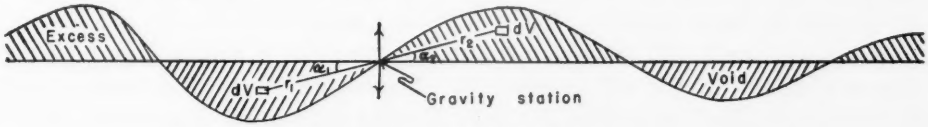

FIG. 1. Nature of the terrain effect.

While there is no assignable distance beyond which the effect of a given topographical feature will become zero, the effects diminish very rapidly with distance so that the preponderant part of the terrain effect is produced by the topography comparatively near the station. Furthermore, in detailed gravity surveys the most significant part of the effect is that which changes from one station to the next. This difference is due principally to the nearby topography, the effect of remote topography being nearly constant at adjacent stations. There is thus some limiting radius about each station beyond which we may safely neglect any terrain effects. The size of this limiting radius will depend upon the roughness of the terrain, the average distance between stations, and the precision to which the corrections must be made. In some cases a radius of not more than 1,000 feet may suffice. In non-mountainous terrain, probably in no case would a radius greater than a few miles be necessary. For such distances it is permissible to neglect the curvature of the earth and to regard the level surface passing through a given station as a plane, which greatly simplifies the calculations.

Regardless of the position of the station with respect to the existing topography, whether upon a high peak or at the bottom of a deep canyon, the terrain effect will always be positive; that is to say that the value of gravity at any given point corresponding to a level topographic surface through that point, will always be greater than for any other topographic configuration. This is true because the filling of any voids below the level of the station will increase the downward attraction and so increase the value of gravity, while the removal of any masses above the level of the station will eliminate an upward attraction and so cause

the value of gravity to increase. The contribution to the terrain effect of either a surplus mass above the level of the station or a void below that level, of volume dV, is given by

$$dg_t = \frac{k\rho dV}{r^2} \sin \alpha \tag{1}$$

where k is the gravitational constant, ρ the average local density, r the radius vector from the station to dV, and α the angle which r makes with the horizontal plane through the station (either above or below) (See Fig. 1).

Integrating equation (1) over the entire volume between the topographic surface and the horizon of the station then gives for the total terrain effect:

$$g_t = k\rho \int_V \frac{dV}{r^2} \sin \alpha, \tag{2}$$

of which every term is an intrinsically positive quantity.

By inspection it will be seen that the magnitude of g_t will be zero for level topography, and that it will progressively increase with increasing roughness of the topography. In virtue of the fact that all terms in equation (2) are intrinsically positive, any given topography can be subjected to a variety of transformations without altering the value of the terrain effect at a given station. Thus, any given topography can be inverted by a mirror-image reflection with respect to the horizon of the station; or, it can be inverted by a rotation of 180° about any horizontal axis, without altering the value of g_t. Hence the terrain effect for a station on the crest of a sharp prismatic ridge is the same as that at the bottom of a V-shaped valley having the same size and shape (inverted) as the ridge. The effect at the bottom of a vertical, rectilinear cliff is the same as that at its top.

The nature of the error produced by the neglect of this effect may be seen as follows. For reasons which need not be considered in detail here, gravity measurements in their "raw" form are unintelligible. Instead, for each station a gravity anomaly representing the difference between the measured value of gravity and a computed "normal" value is employed for interpretation purposes. The usual anomaly is obtained by the equation

$$g_a = g_o - g_n, \tag{3}$$

where g_a is the gravity anomaly, g_o the observed value, and g_n the normal value of gravity for a given station. The normal value of gravity is computed on the basis of the assumption that the topography is level and has the same elevation as the station. Thus, to be strictly comparable, the observed value should also correspond only to level topography. This can be achieved by adding to the observed value of gravity the terrain correction for the station. We should then obtain the anomaly

$$g_a' = g_0 + g_t - g_n, \tag{4}$$

which would be free of terrain influence.

Comparison of this with equation (3) shows that

$$g_a' = g_a + g_t,$$

or

$$g_a = g_a' - g_t. \tag{5}$$

Hence the anomaly g_a is systematically less than the desired anomaly g_a' by an amount equal to the terrain correction. The value of the terrain correction is zero for level topography, and increases with the roughness of the topography. Consequently, as W. Hafner has pointed out, if a gravity survey is made over a region of alternate level and rough areas the uncorrected anomaly g_a, due solely to the terrain, will assume maximum values over the level areas and minimum values over the rough areas, as in Figure 2, which might lead to false interpretation and to an expensive follow-up program if the cause of the variations were not recognized.

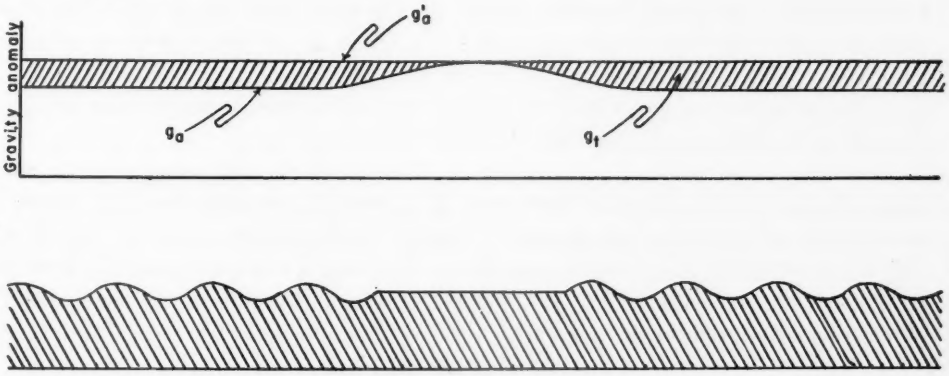

FIG. 2. Fictitious anomaly produced by alternating rough and flat topography without terrain corrections.

COMPUTATION OF TERRAIN EFFECTS

Equation (2) is the general expression for the terrain effect. Templates and tables for its evaluation in three-dimensional topography have been presented by Hammer.[1] Three-dimensional topography, however, is laborious to compute, and moreover, does not lend itself readily to the construction of significant profiles, yet the order of magnitude of the terrain effect for analogous two- and three-dimensional features is the same. For example the terrain effect at the apex of a circular cone with a 30° slope is 1.5 times as great as that at the crest of a 30° ridge of the same height.

[1] Sigmund Hammer, "Terrain Corrections for Gravimeter Stations," *Geophysics*, IV (1939), 184–194.

In view of these several considerations the computations presented herein have been restricted to two-dimensional features, for which there are altogether forty-seven separate profiles. The method employed in making these computations was that described in a companion paper.[2] It is of passing interest to note that these forty-seven profiles were computed and drawn by a single computer in less than two weeks, and the drafting was said to have required more time than the computations.

The manner in which the profiles are presented requires some explanation. All calculations are based on a rock density of 2.0 gm/cm^3, which is near the average density of surface sediments. The results are presented in a dimensionless manner so that each separate chart represents an infinity of features having the same shape but varying in size. Moreover, as was pointed out earlier, the terrain effect at a given station is invariant with respect to an inversion of the topography. Therefore, although only positive or ridgelike features are presented, the corresponding families of valleys and canyons is obtained by turning these upside-down.

The profiles have all been constructed on the basis of a unit of length of 100 feet. The altitude a (in terms of this unit) is taken as a characteristic length in each case, and the abscissas are expressed in multiples of a, that is, $1a$, $2a$, $3a$, etc. The ordinates are given in terms of a quantity G which represents the terrain correction in milligals when a has the value unity (100 feet).

The terrain correction for any other sized feature of the same shape can be obtained from considerations of similarity. For example, consider two two-dimensional features which are geometrically similar and have the same density, but differ in size. Let l_1 be a given length in the first and l_2 the corresponding length in the second, and let g_1 and g_2 be the gravitational attractions of the two masses at corresponding points. In this case

$$\left.\begin{aligned} g_1 &= 2k\rho\left[\iint_{S_1} d\theta dz\right]_1, \\ g_2 &= 2k\rho\left[\iint_{S_2} d\theta dz\right]_2. \end{aligned}\right\} \tag{6}$$

From these equations the ratio of g_2 to g_1 will be

$$g_2/g_1 = l_2/l_1. \tag{7}$$

Thus the gravitational attraction of a two-dimensional mass will increase linearly with its increase of size.

Making use of this fact, and taking a feature with a 100-foot altitude as the first of two bodies, then the terrain effect at a corresponding point of any other similar feature, but differing in size by an enlargement factor a, will be given by

$$\Delta g = aG. \tag{8}$$

[2] M. King Hubbert, "A Line-Integral Method of Computing the Gravimetric Effects of Two-Dimensional Masses," *Geophysics*, XIII (1948), 215–225.

All of the terrain charts (Figs. 3 to 50) have been constructed on this basis.

As an example of their use, let us determine the terrain correction for a station at a distance 450 feet from a vertical cliff 150 feet high. Here $a = 1.5$ and the dis-

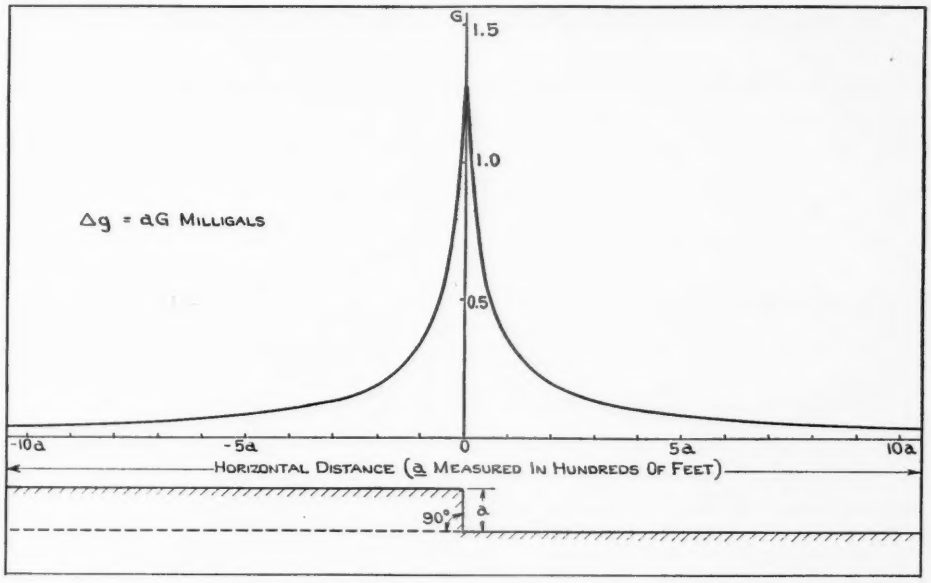

Fig. 3. Effect of vertical cliff.

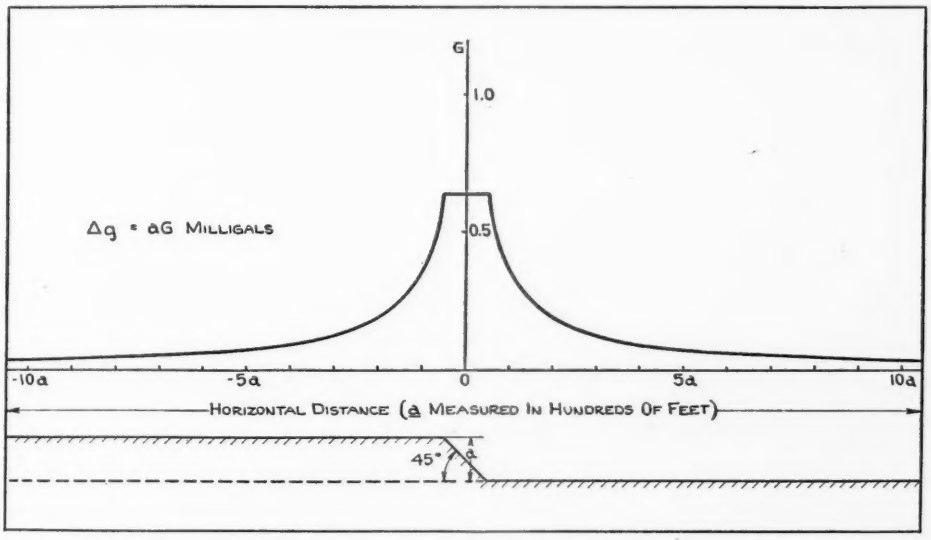

Fig. 4. Effect of a 45° slope.

tance of the station from the cliff is $3a$. Referring to the appropriate chart (Fig. 3) for G, and employing equation (8),

$$\Delta g = aG = 1.5 \times 0.14 = 0.21 \text{ milligals.}$$

By means of these charts, gravity parties in the field can determine quickly

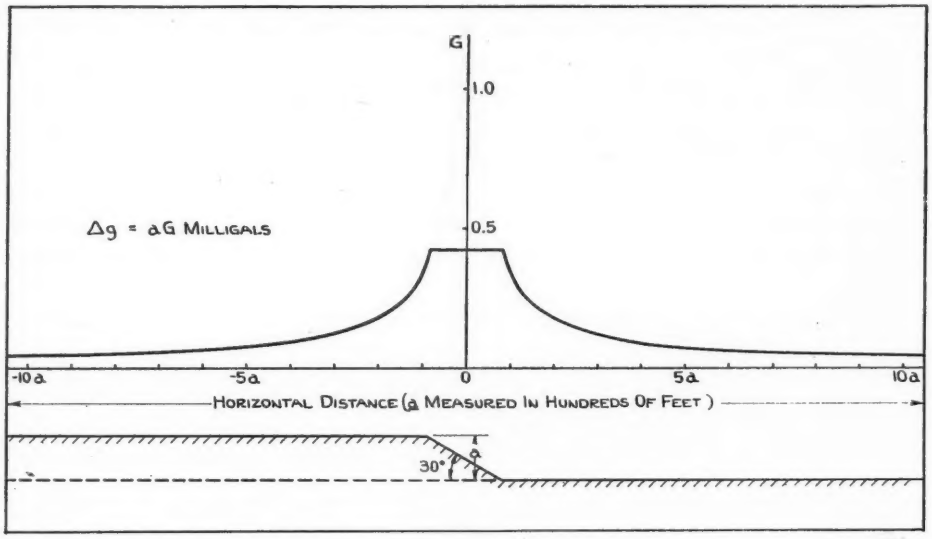

Fig. 5. Effect of a 30° slope.

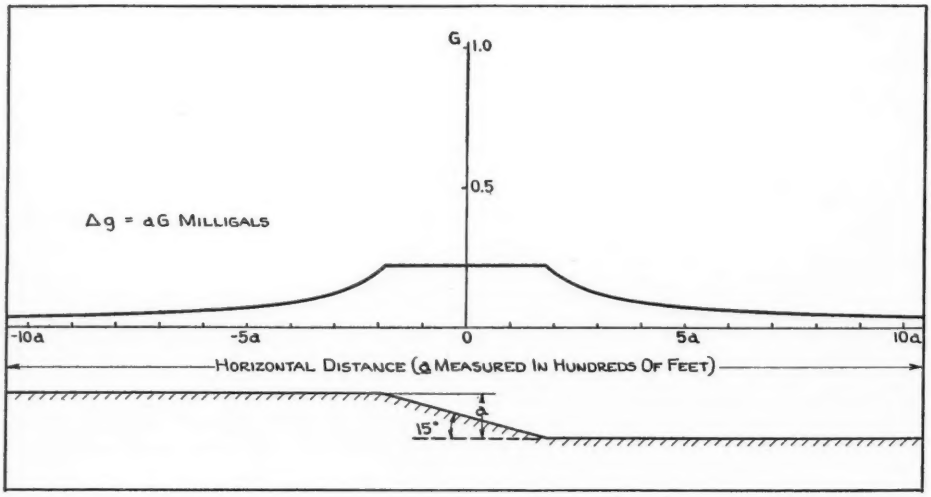

Fig. 6. Effect of a 15° slope.

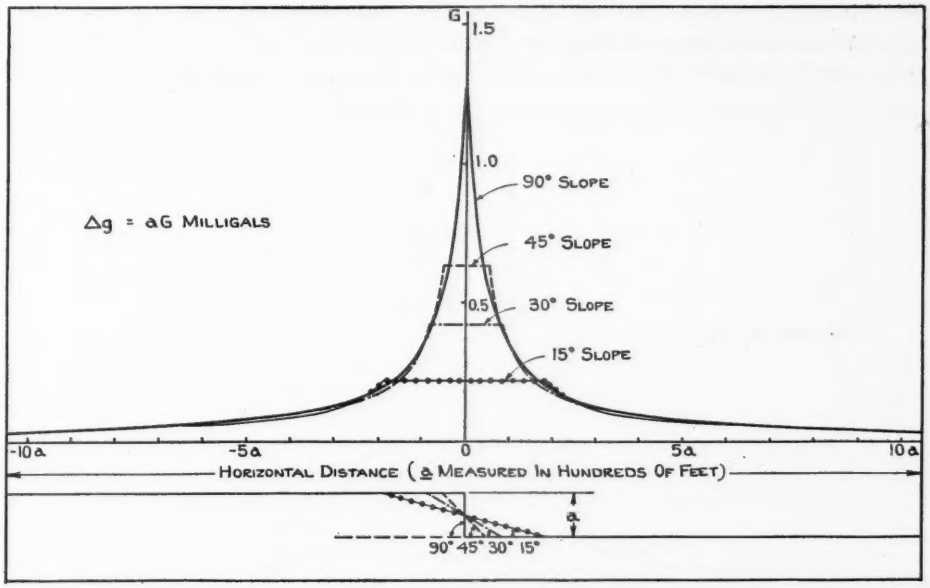

FIG. 7. Comparison of effects of slopes of 15°, 30°, 45°, and 90°.

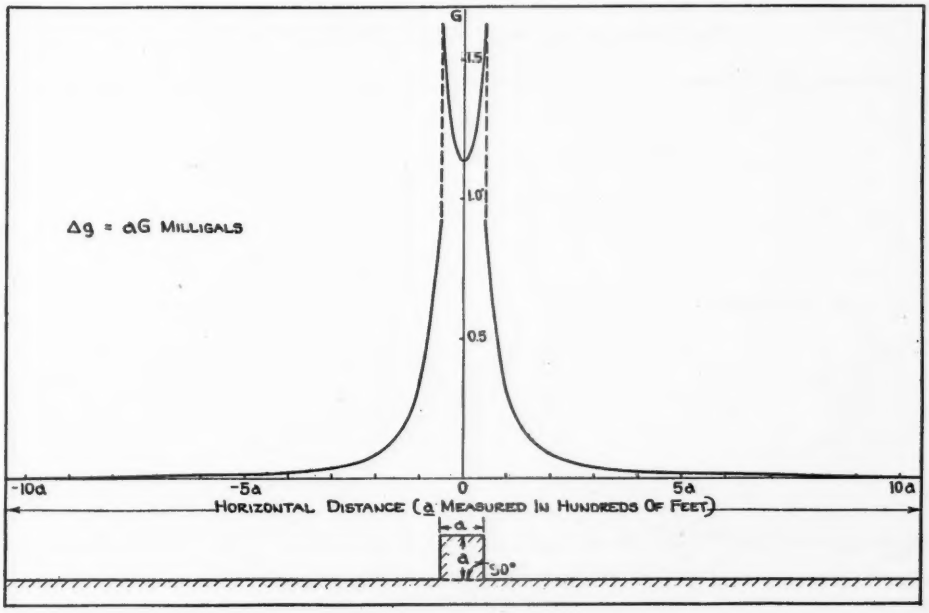

FIG. 8. Effect of ridge, crest width a, slope of sides 90°.

the types of locations which will give sharply peaked values of terrain error, and the approximate distances from these points it is necessary to remain if terrain errors are to be kept within prescribed limits. Likewise interpretive staffs in the

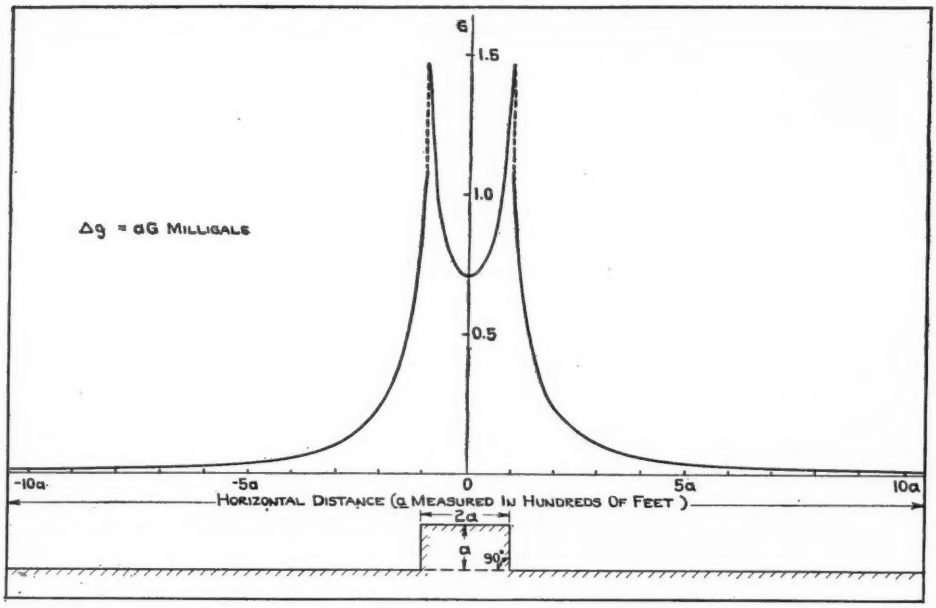

Fig. 9. Effect of ridge, crest width $2a$, slope of sides 90°.

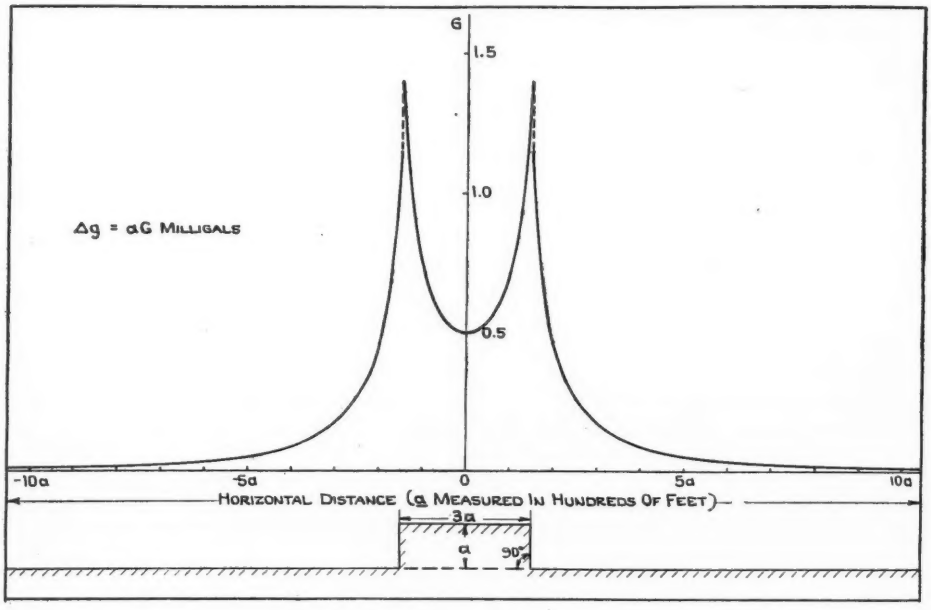

Fig. 10. Effect of ridge, crest width $3a$, slope of sides 90°.

office can determine by inspection the approximate magnitudes of terrain effects from given topography and allowances can be made for this before attributing significance to anomalies of small magnitude.

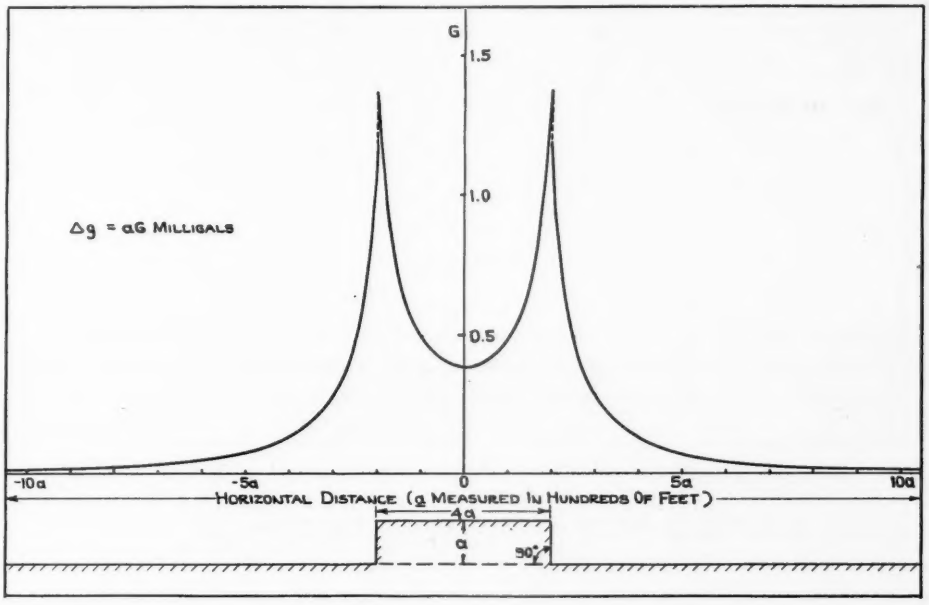

FIG. 11. Effect of ridge, crest width $4a$, slope of sides 90°.

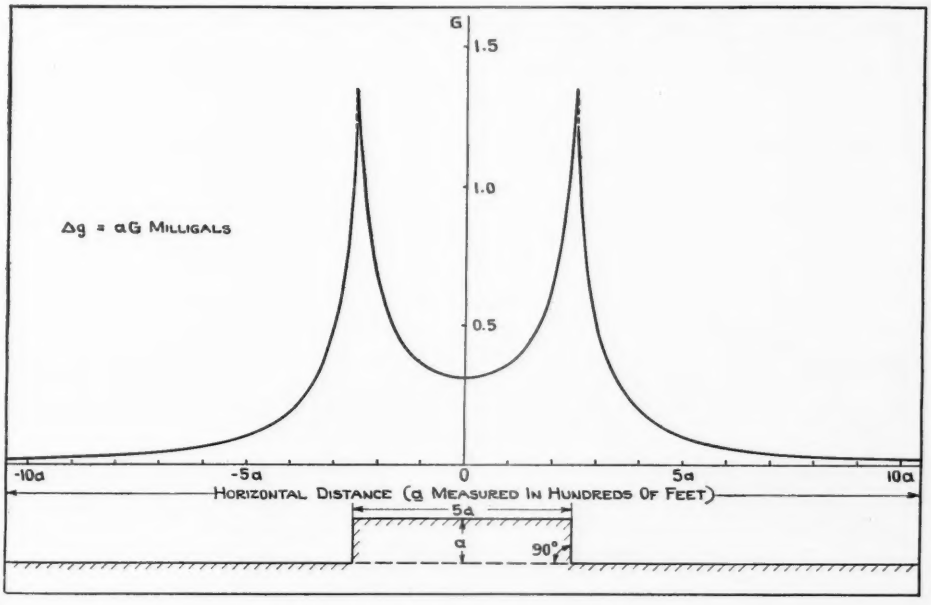

FIG. 12. Effect of ridge, crest width $5a$, slope of sides 90°.

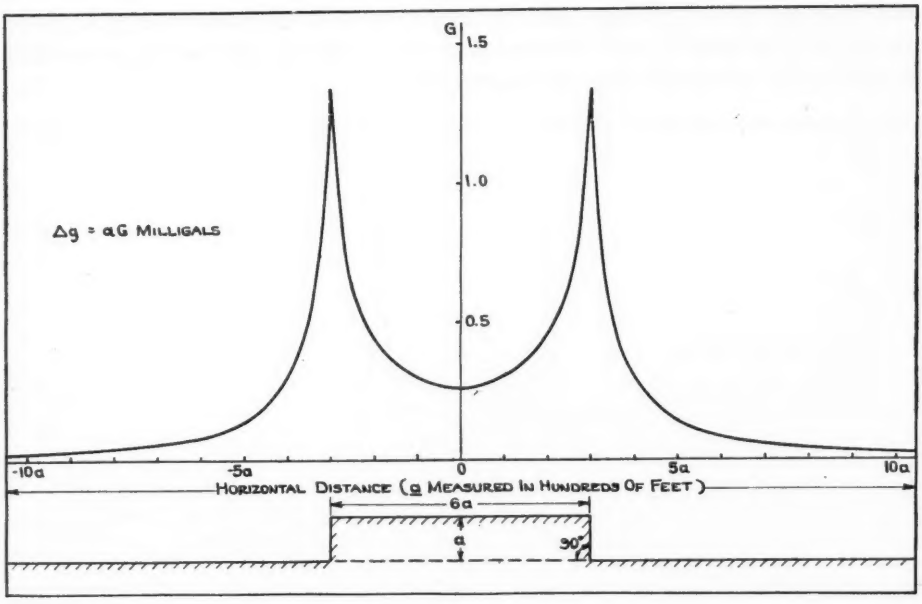

FIG. 13. Effect of ridge, crest width $6a$, slope of sides 90°.

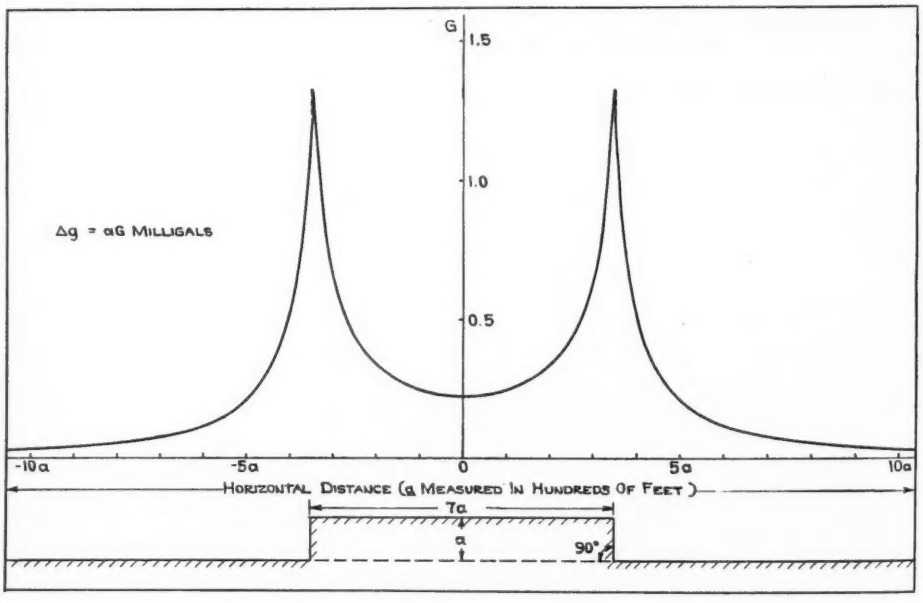

FIG. 14. Effect of ridge, crest width $7a$, slope of sides 90°.

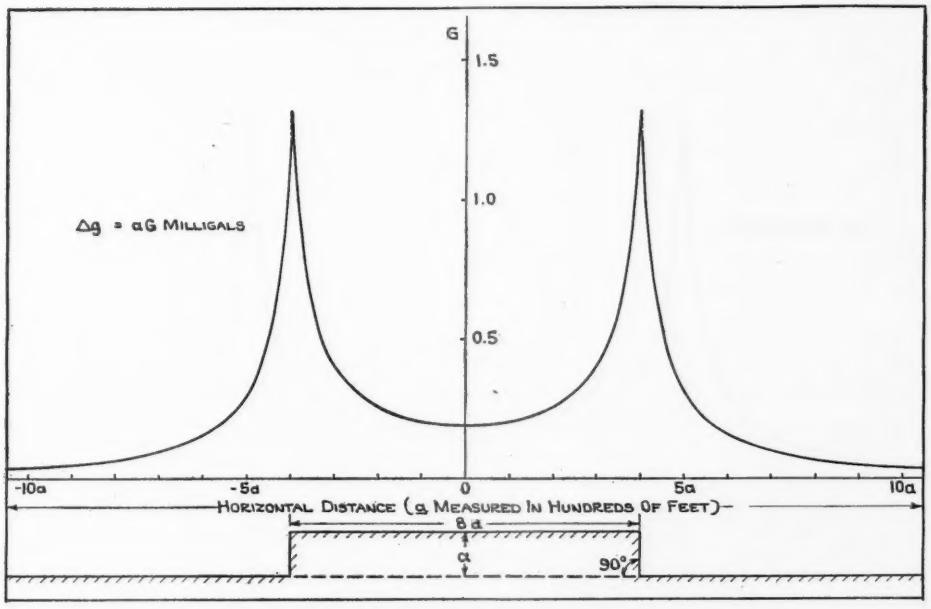

FIG. 15. Effect of ridge, crest width $8a$, slope of sides 90°.

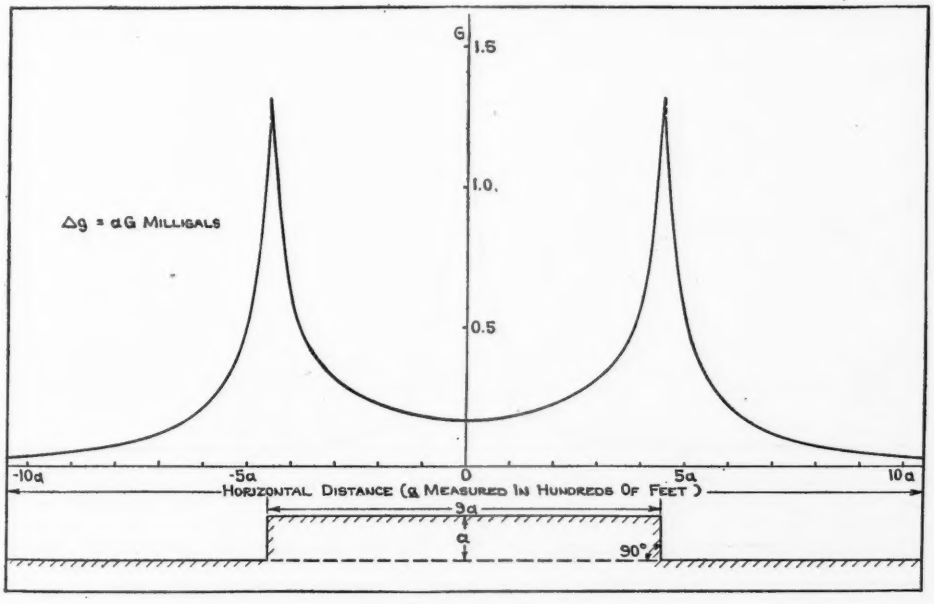

FIG. 16. Effect of ridge, crest width $9a$, slope of sides 90°.

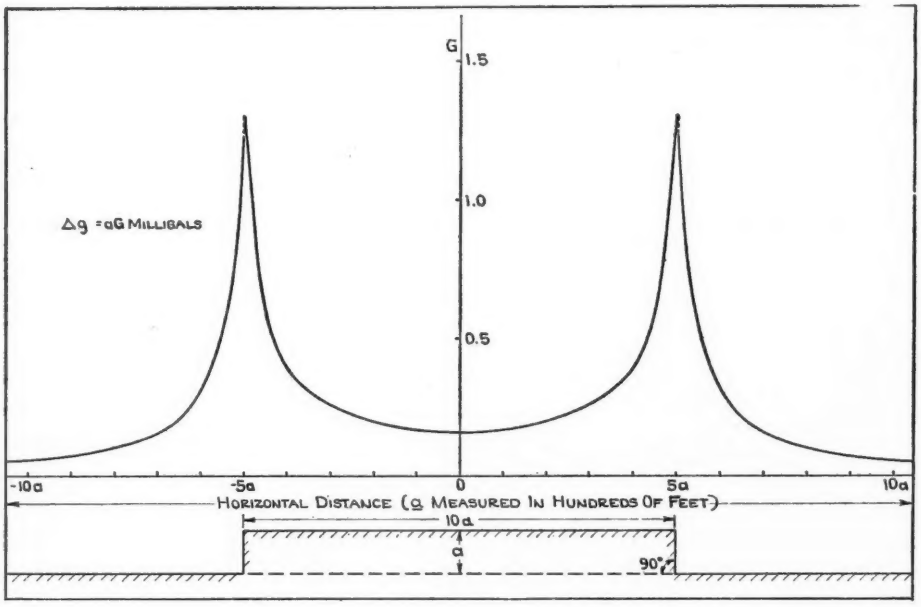

FIG. 17. Effect of ridge, crest width 10*a*, slope of sides 90°.

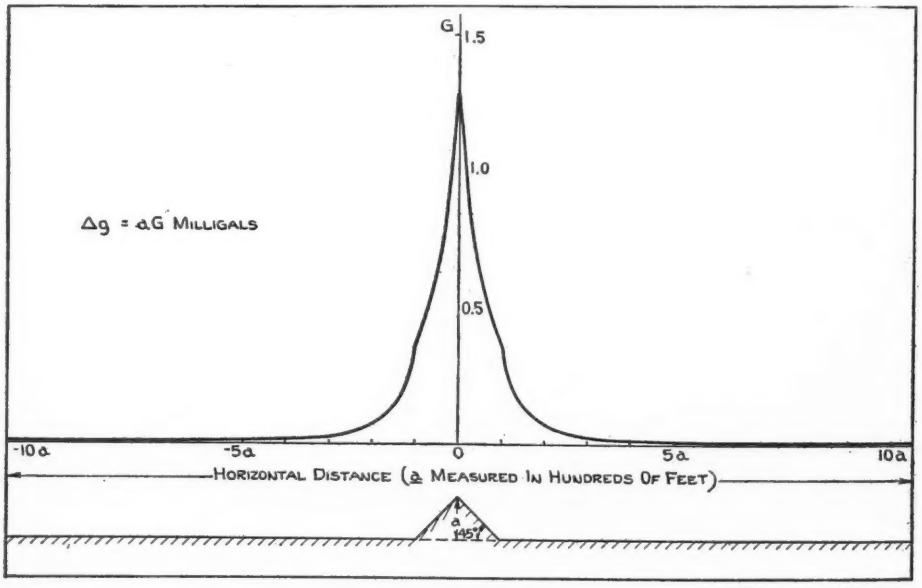

FIG. 18. Effect of sharp ridge, slope of sides 45°.

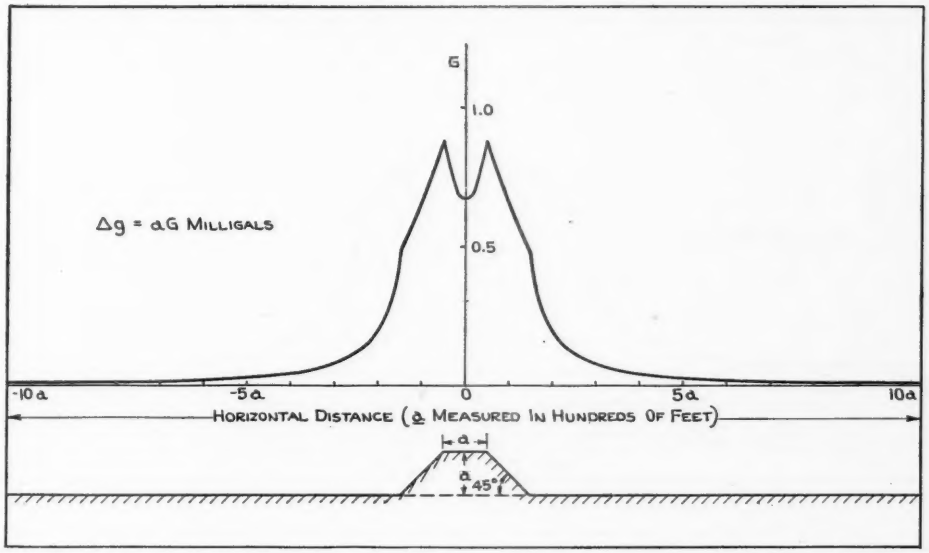

FIG. 19. Effect of ridge, crest width a, slope of sides 45°.

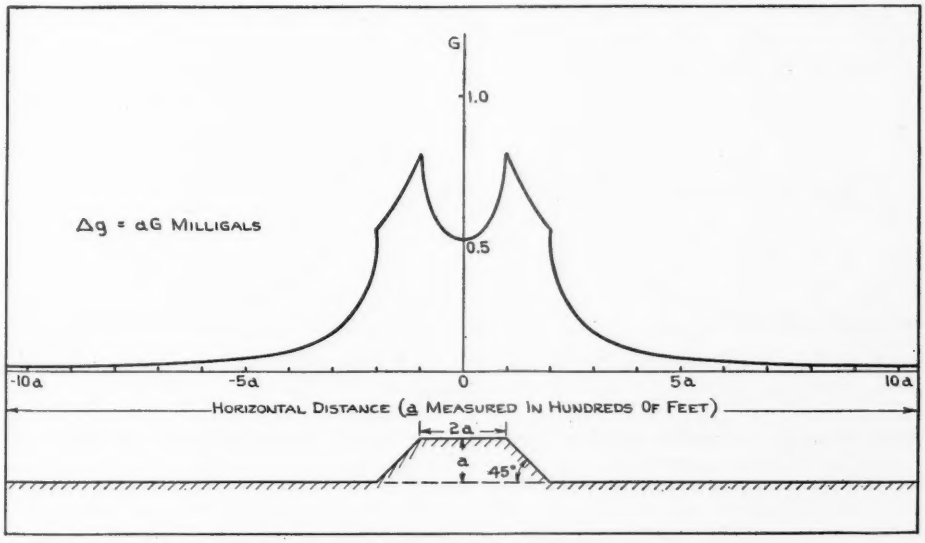

FIG. 20. Effect of ridge, crest width $2a$, slope of sides 45°.

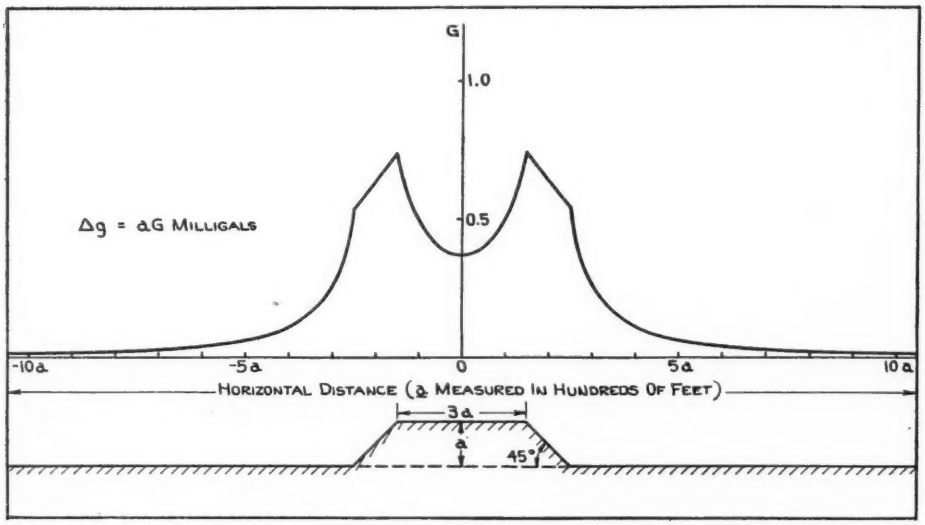

FIG. 21. Effect of ridge, crest width $3a$, slope of sides 45°.

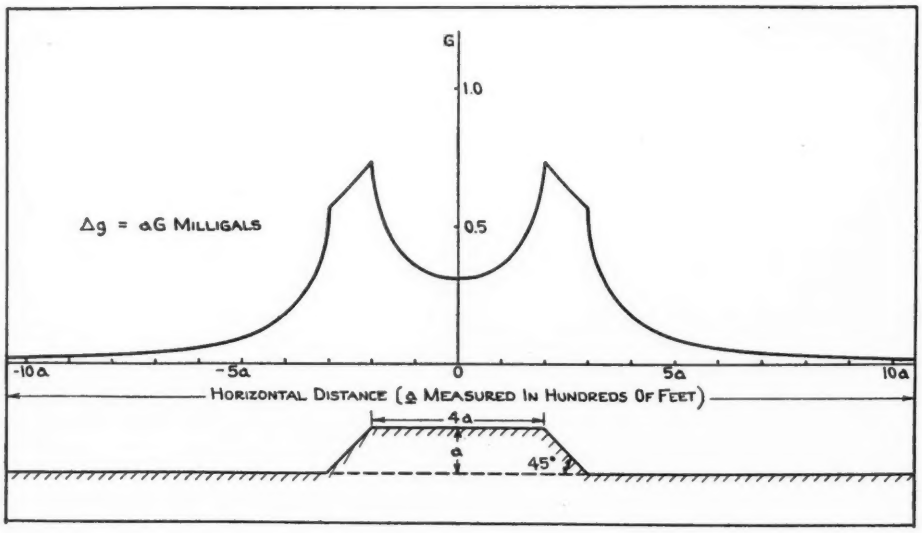

FIG. 22. Effect of ridge, crest width $4a$, slope of sides 45°.

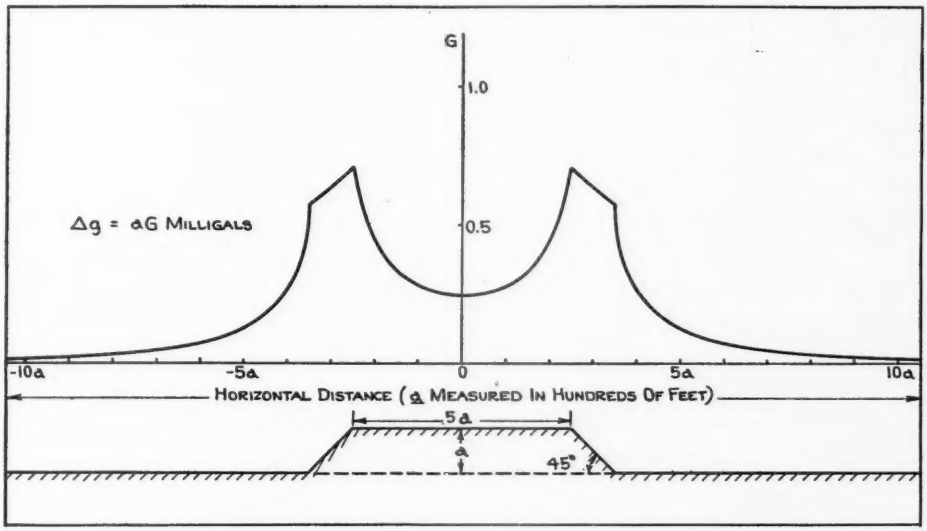

FIG. 23. Effect of ridge, crest width $5a$, slope of sides 45°.

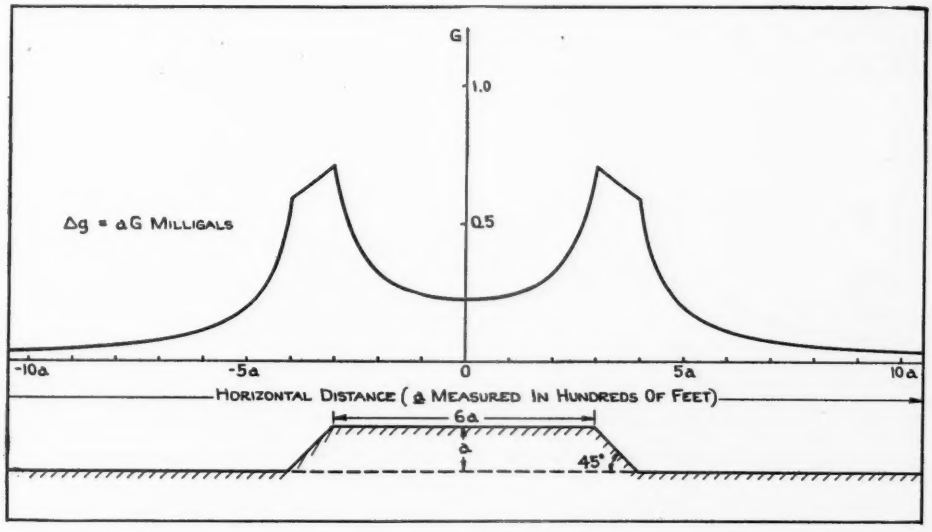

FIG. 24. Effect of ridge, crest width $6a$, slope of sides 45°.

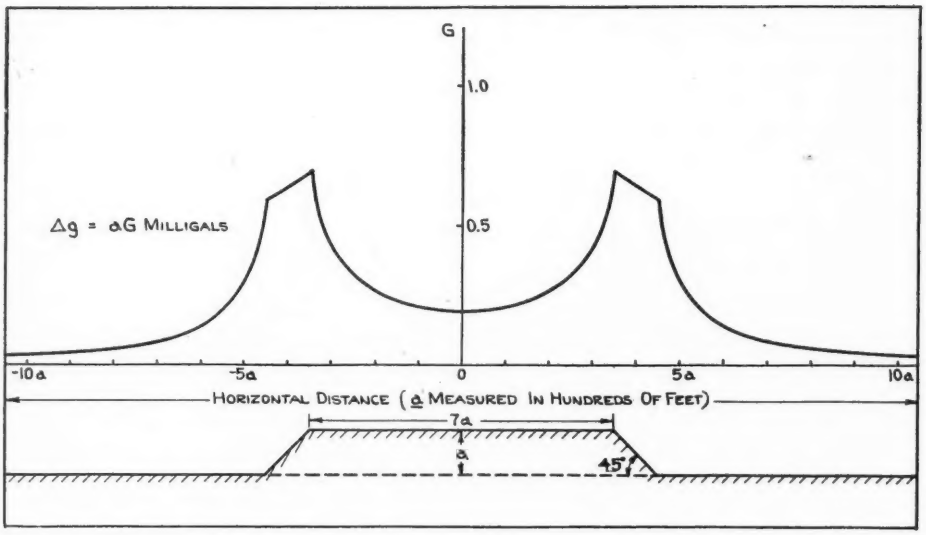

Fig. 25. Effect of ridge, crest width $7a$, slope of sides 45°.

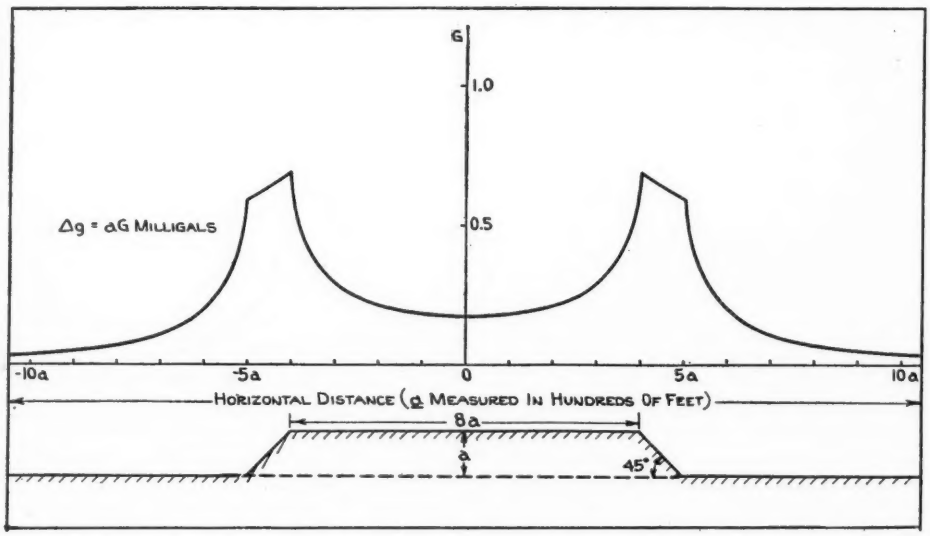

Fig. 26. Effect of ridge, crest width $8a$, slope of sides 45°.

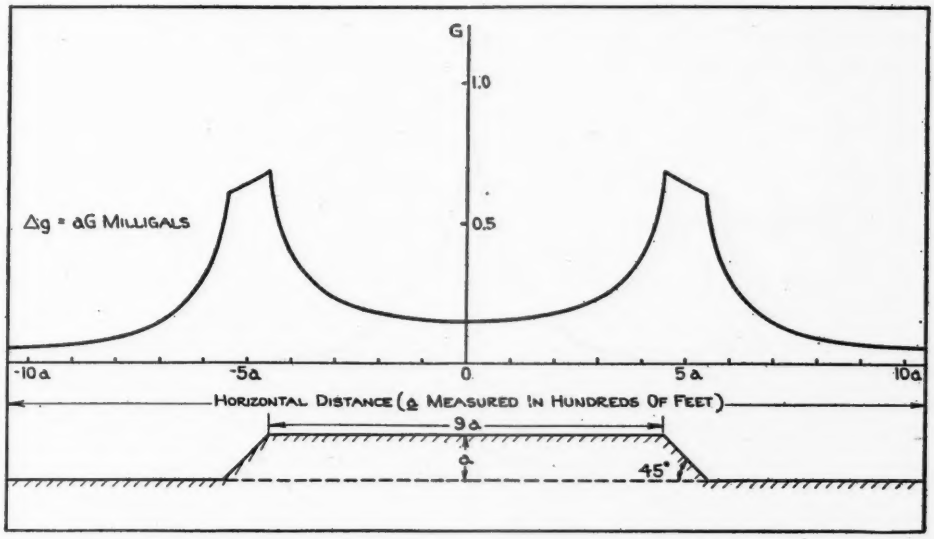

FIG. 27. Effect of ridge, crest width $9a$, slope of sides 45°.

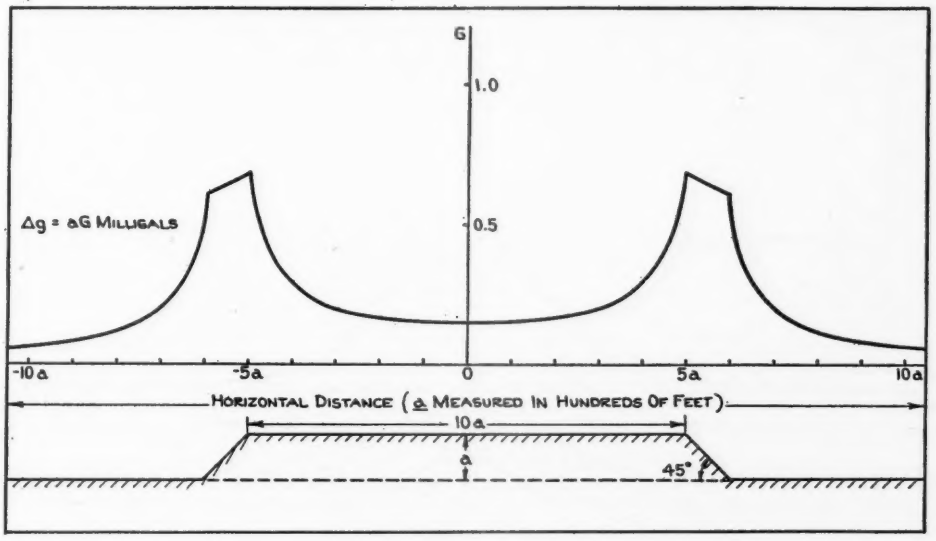

FIG. 28. Effect of ridge, crest width $10a$, slope of sides 45°.

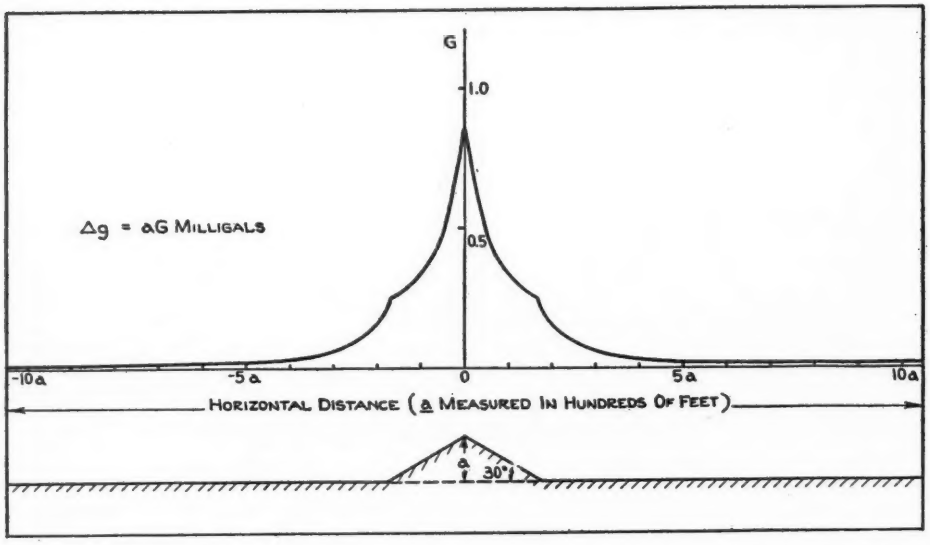

FIG. 29. Effect of sharp ridge, slope of sides 30°.

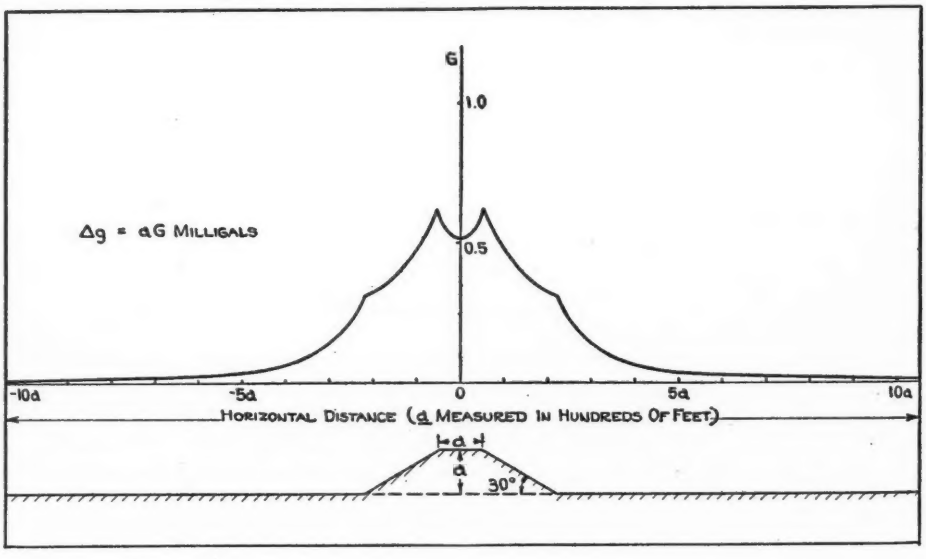

FIG. 30. Effect of ridge, crest width *a*, slope of sides 30°.

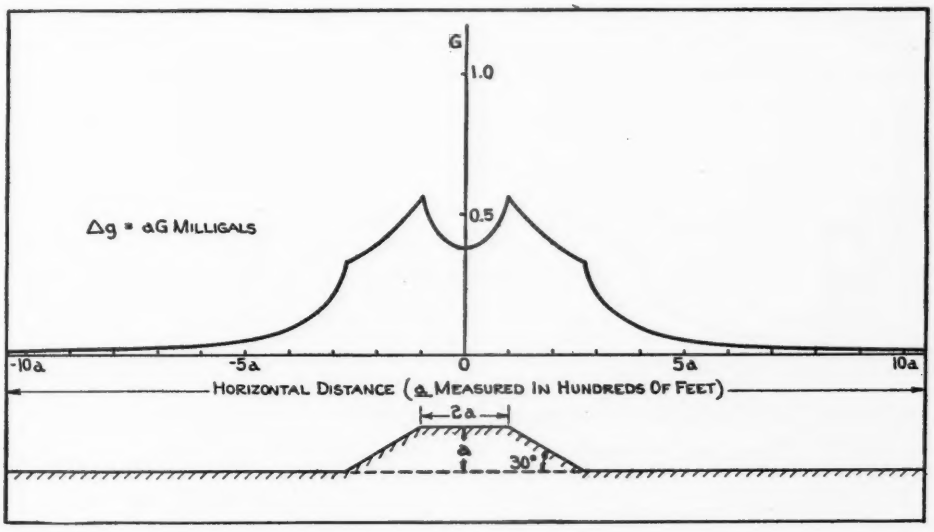

FIG. 31. Effect of ridge, crest width $2a$, slope of sides 30°.

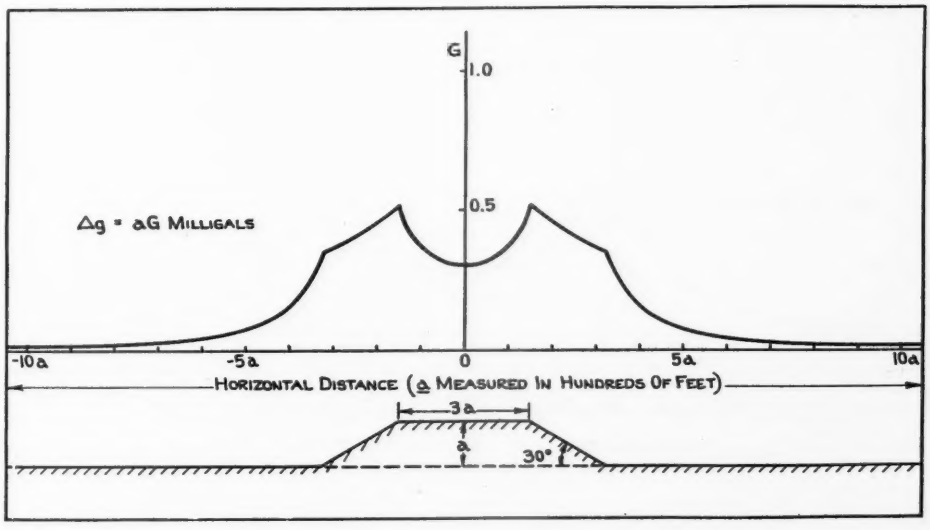

FIG. 32. Effect of ridge, crest width $3a$, slope of sides 30°.

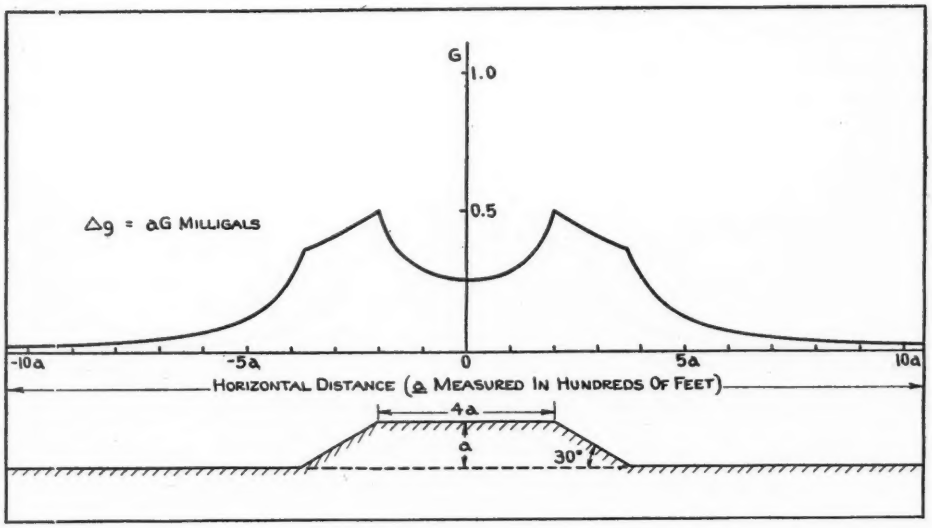

FIG. 33. Effect of ridge, crest width $4a$, slope of sides 30°.

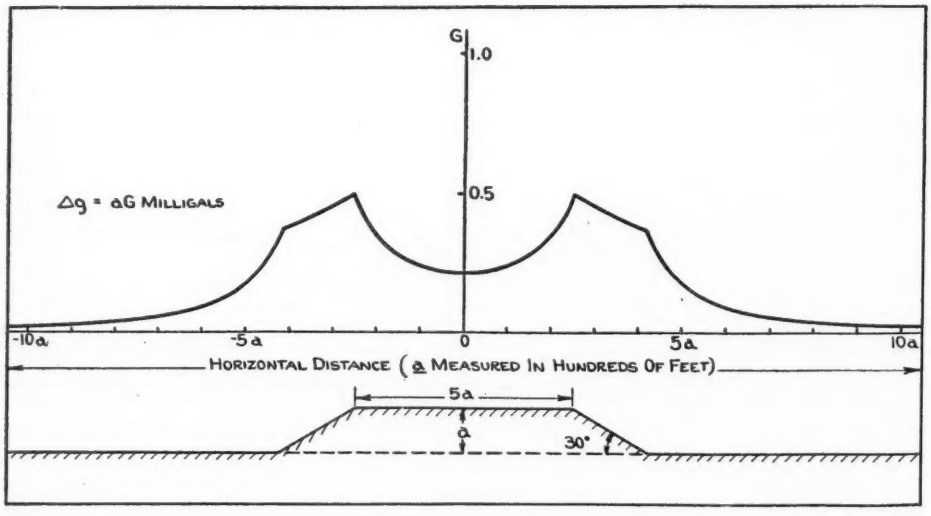

FIG. 34. Effect of ridge, crest width $5a$, slope of sides 30°.

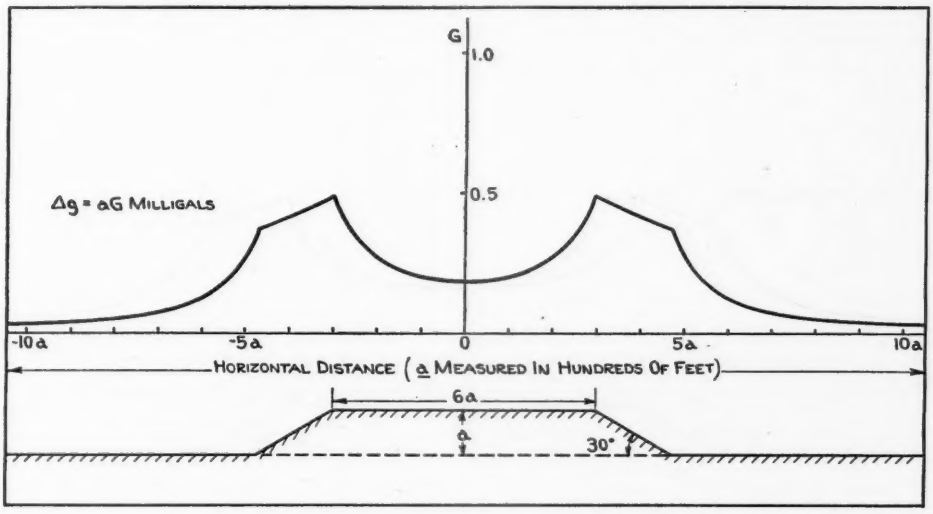

FIG. 35. Effect of ridge, crest width $6a$, slope of sides 30°.

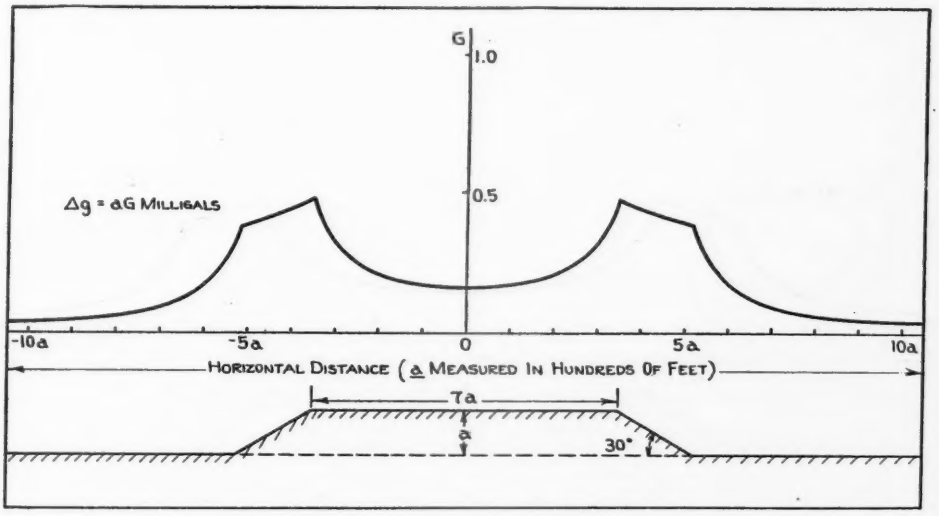

FIG. 36. Effect of ridge, crest width $7a$, slope of sides 30°.

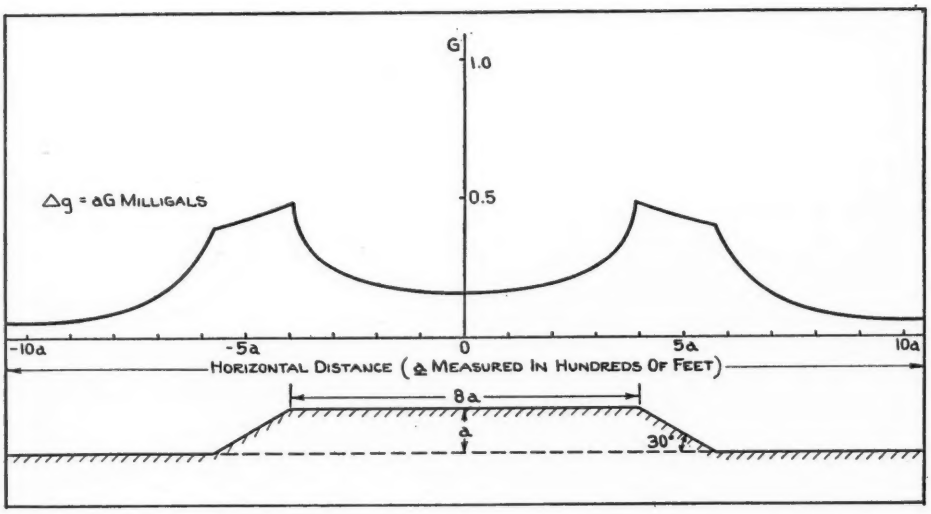

FIG. 37. Effect of ridge, crest width 8*a*, slope of sides 30°.

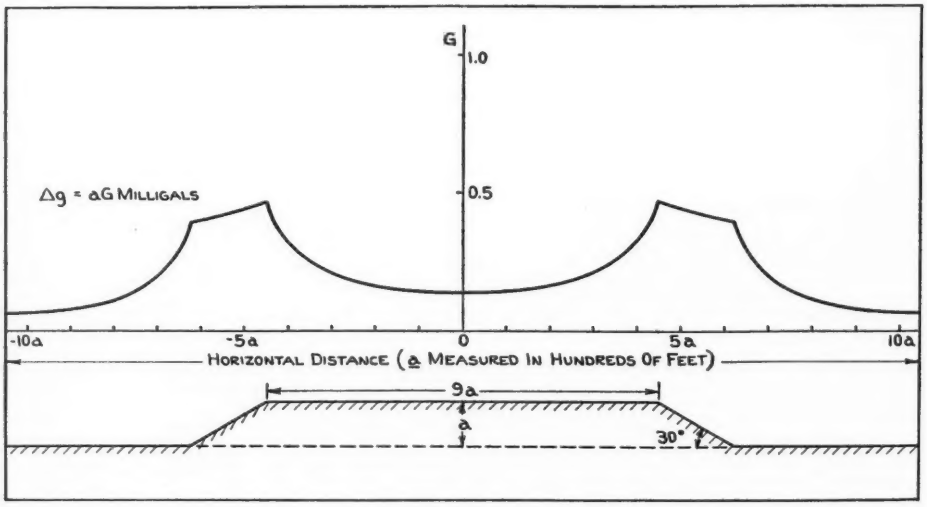

FIG. 38. Effect of ridge, crest width 9*a*, slope of sides 30°.

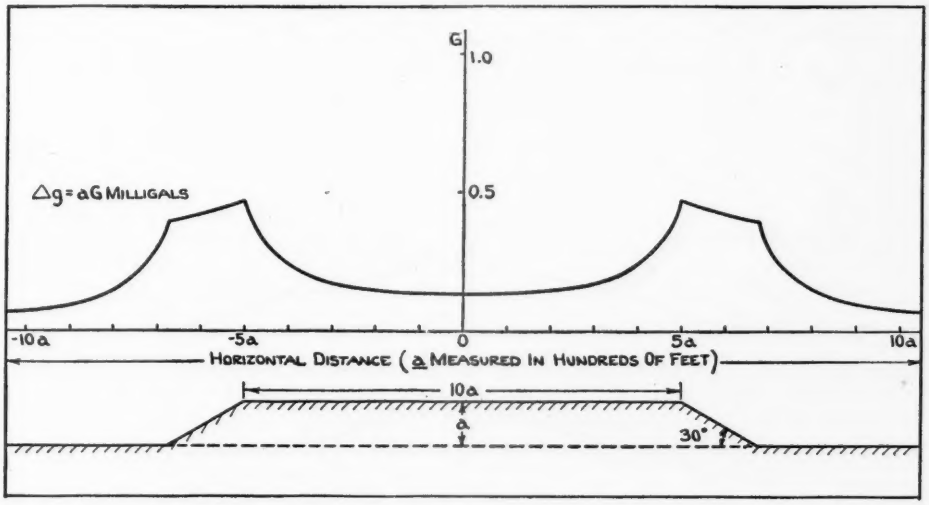

FIG. 39. Effect of ridge, crest width 10*a*, slope of sides 30°.

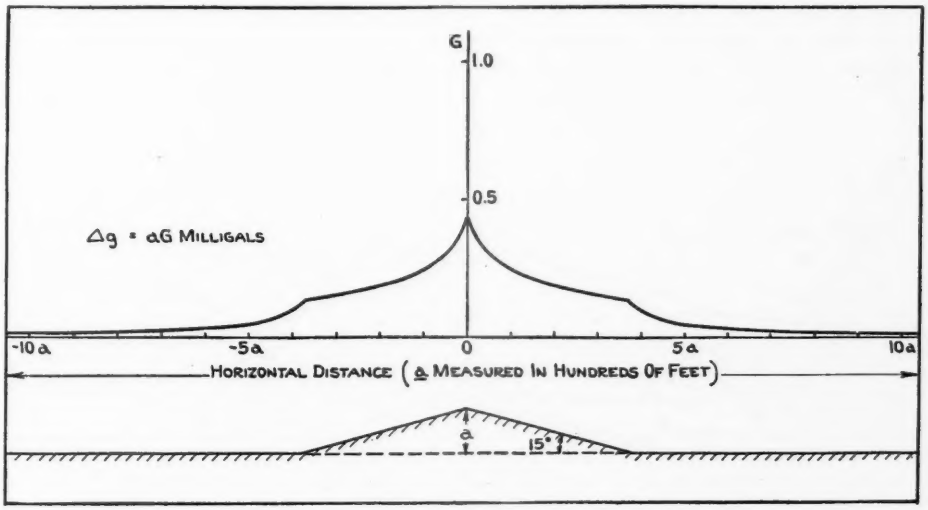

FIG. 40. Effect of sharp ridge, slope of sides 15°.

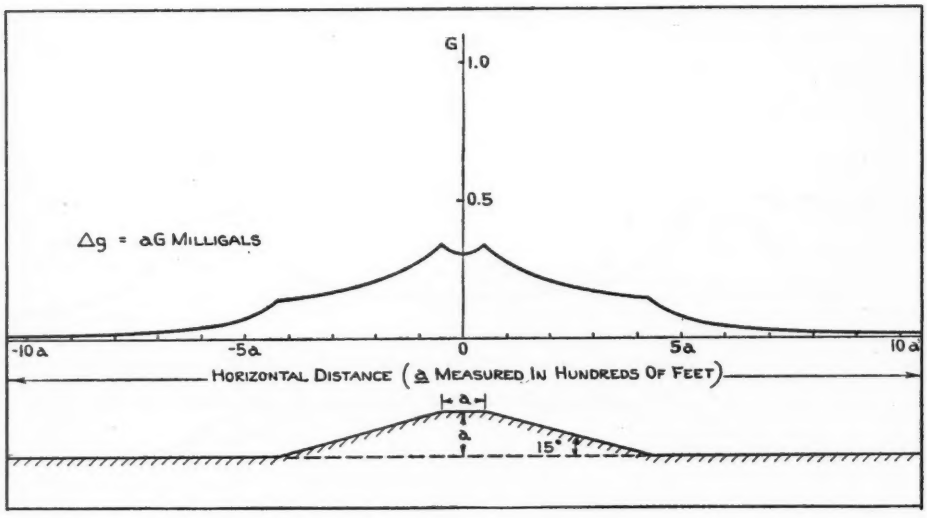

FIG. 41. Effect of ridge, crest width a, slope of sides 15°.

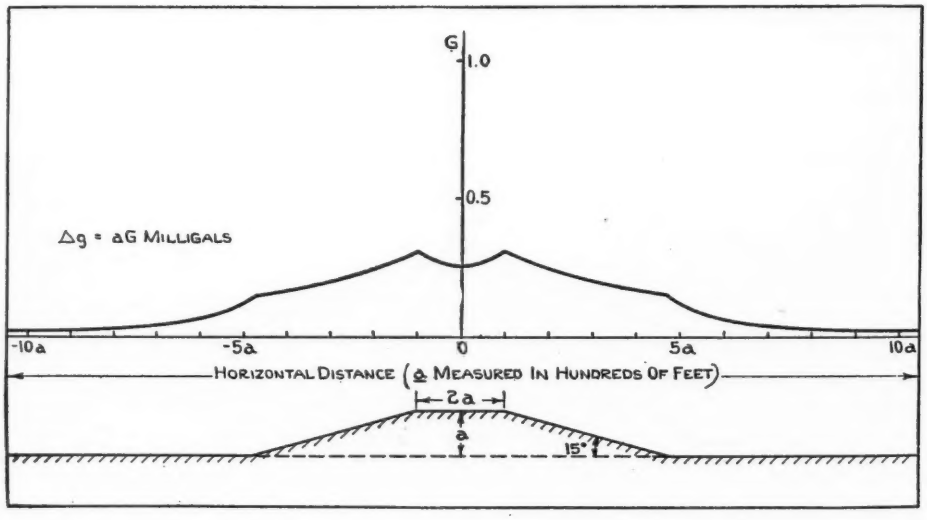

FIG. 42. Effect of ridge, crest width $2a$, slope of sides 15°.

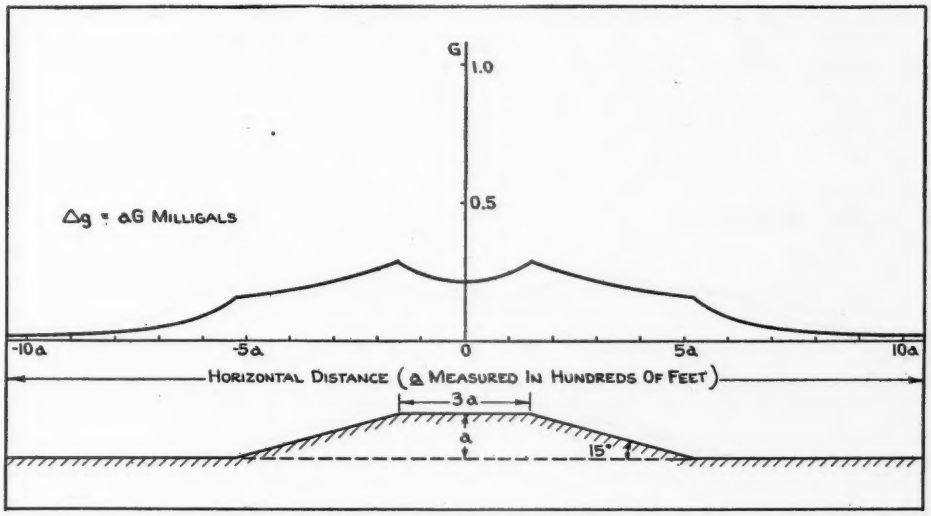

FIG. 43. Effect of ridge, crest width $3a$, slope of sides 15°.

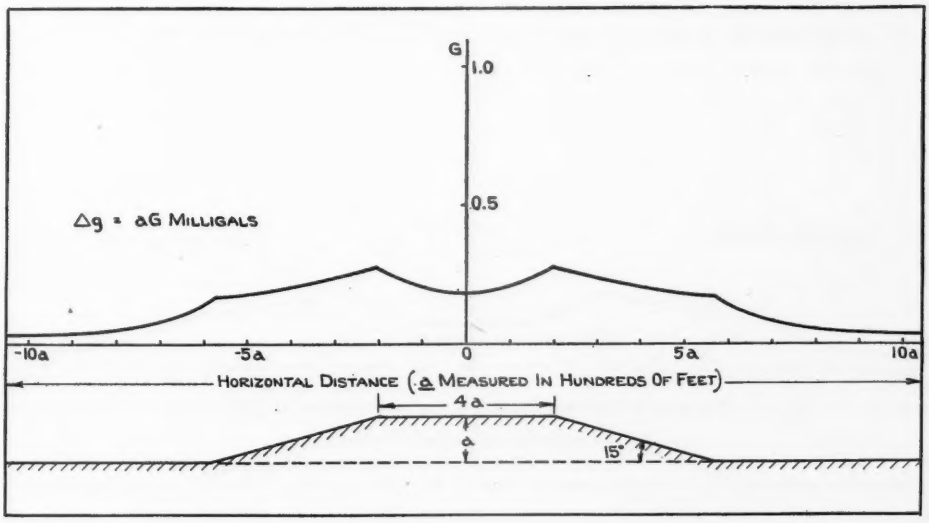

FIG. 44. Effect of ridge, crest width $4a$, slope of sides 15°

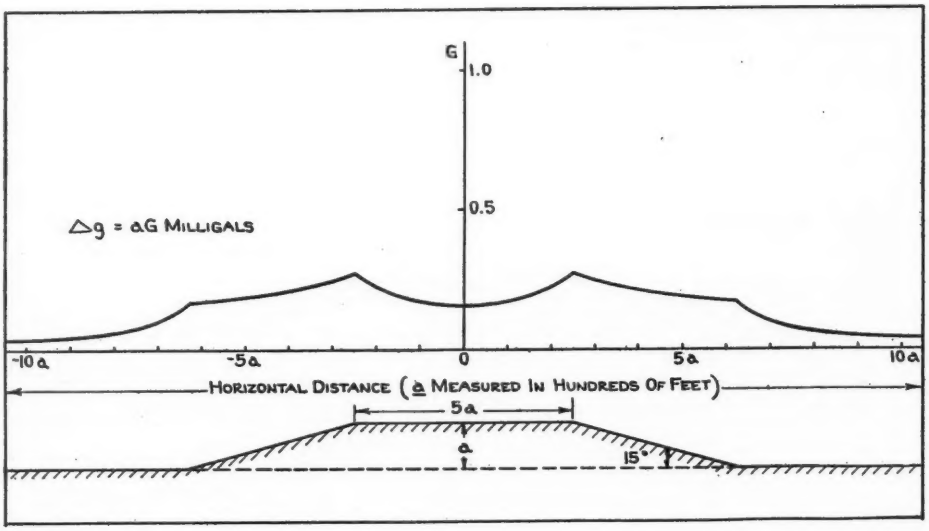

FIG. 45. Effect of ridge, crest width $5a$, slope of sides 15°.

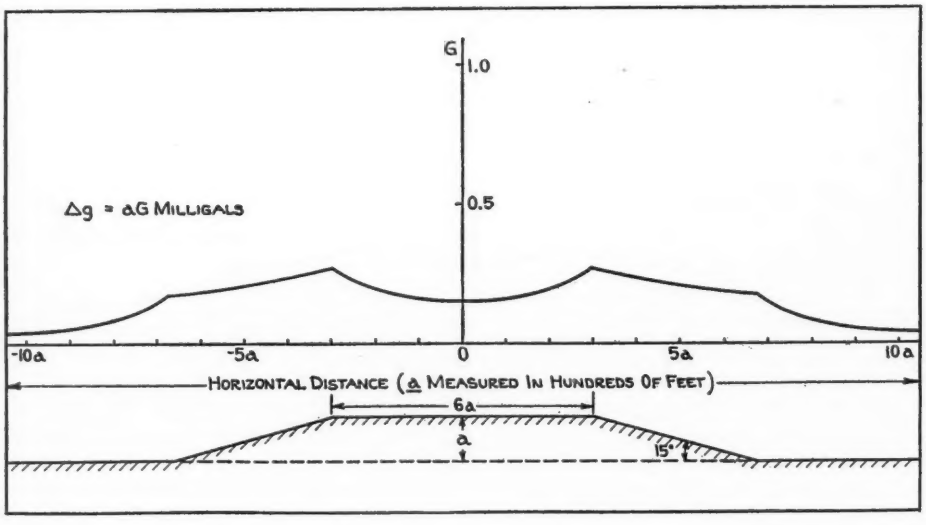

FIG. 46. Effect of ridge, crest width $6a$, slope of sides 15°.

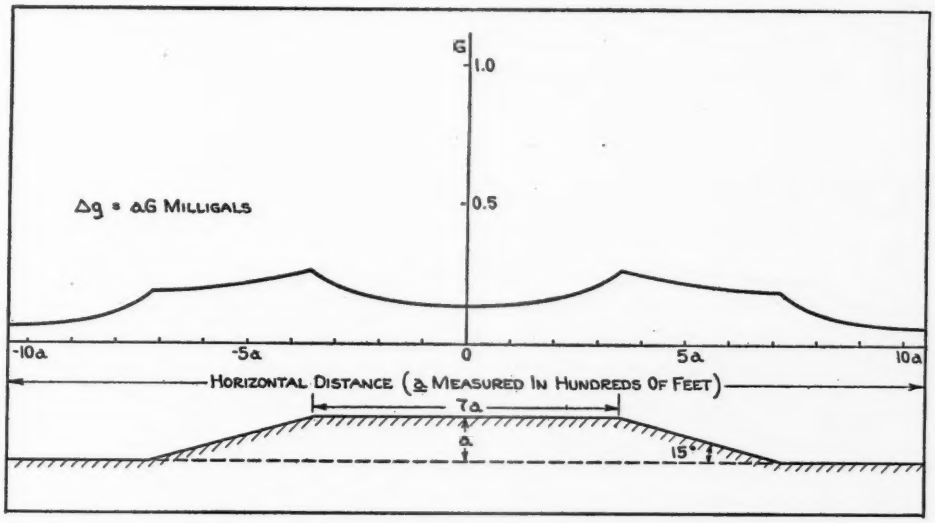

FIG. 47. Effect of ridge, crest width $7a$, slope of sides 15°.

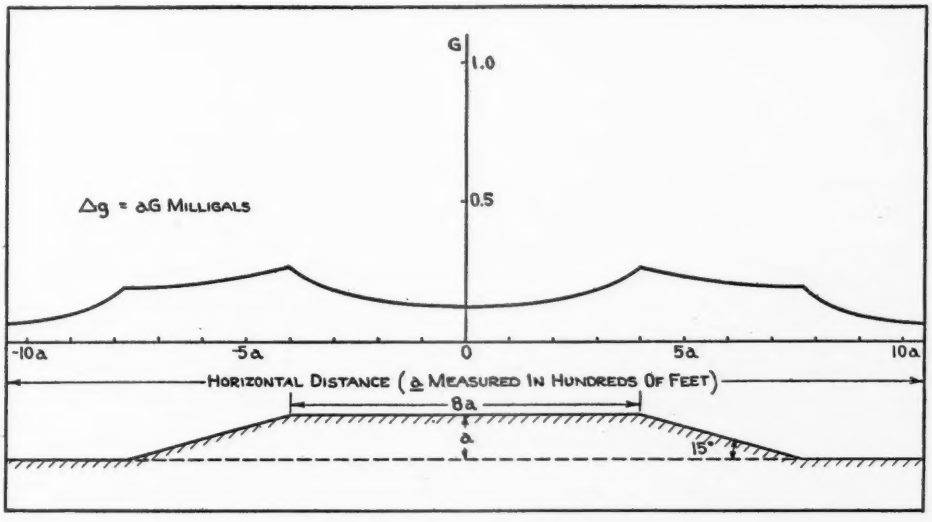

FIG. 48. Effect of ridge, crest width $8a$, slope of sides 15°.

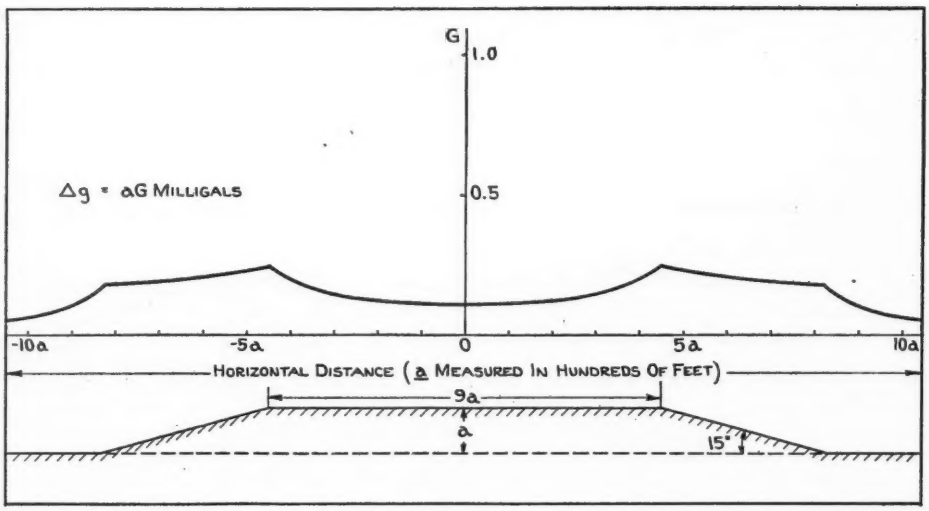

FIG. 49. Effect of ridge, crest width 9*a*, slope of sides 15°.

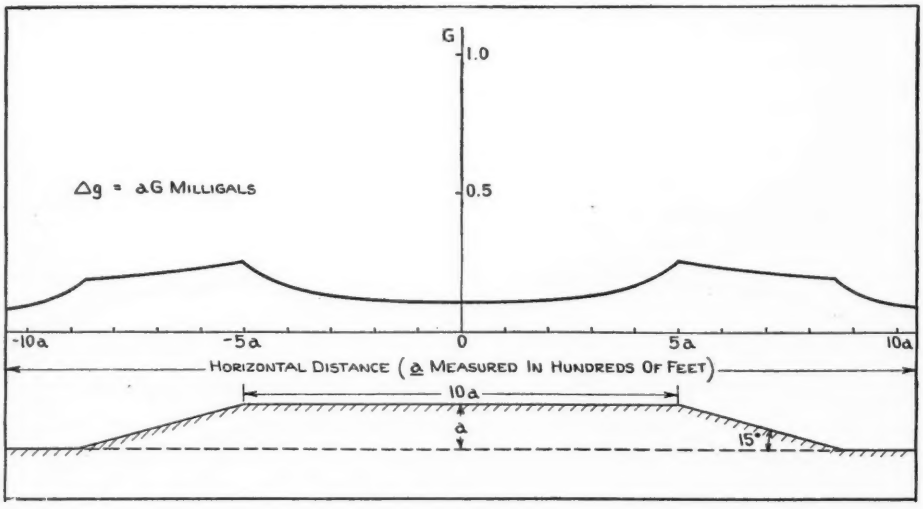

FIG. 50. Effect of ridge, crest width 10*a*, slope of sides 15°.

A NOTE ON TERRAIN CORRECTIONS*

H. C. BICKEL†

ABSTRACT

A means is presented for empirically determining the areal extent within which terrain corrections are appreciable in any given area. An example is given to show how the same device can be extended to decrease the labor of making terrain corrections in extremely rugged areas.

All terrain-correction calculations referred to in this paper make use of the system published by Hammer.[1] It is assumed that improved interpretation justifies making terrain corrections and that a suitable topographic map is available.

To investigate an area suspected to require terrain corrections, five to ten stations are chosen for complete terrain-correction calculations. The stations are chosen over as wide an area as convenient and should have individual elevations well distributed over the elevation range to be encountered in the course of the survey, including the maximum and minimum elevations. The corrections for each compartment within any given zone are then totaled to give the correction for the entire zone. This is repeated for all zones for all the sample stations. The total Zone-*M* correction for each station is plotted against the elevation of the station and a curve is drawn through the points. The points will generally track very well on a smooth shallow parabolic curve, because only the most severe topographic conditions cause corrections to vary appreciably in Hammer's outer Zone *M*.

The same procedure is followed for Zone *L* and then for Zones *K* and *J* and *I* progressively. It will be found that as this treatment is applied to successive zones, the closer in the zone is, the deeper the parabolic curve becomes and the points track less well on the curve. The amount by which the points fall off the smooth curve is a measure of the amount of possible error introduced if the curve is used to actually make a total terrain correction within the zone at each of the remaining stations in the gravity survey. Eventually, a zone will be reached where the points track so poorly that no reasonable curve can be drawn. This is the zone within which it is essential to make individual terrain corrections at every station and outside of which the corrections can be approximated by reference to the curves already drawn or else the correction can be ignored because the curves indicate the correction to be negligible.

A typical set of curves is shown in Figure 1 where corrections in Zones *M* and *L* can be ignored, corrections in Zones *K* and *J* can be quite adequately esti-

* Manuscript received by the Editor, November 24, 1947.

† Seismograph Service Corporation, Tulsa, Oklahoma.

[1] Sigmund Hammer, "Terrain Corrections for Gravimeter Stations," *Geophysics*, IV (1939), 184–194.

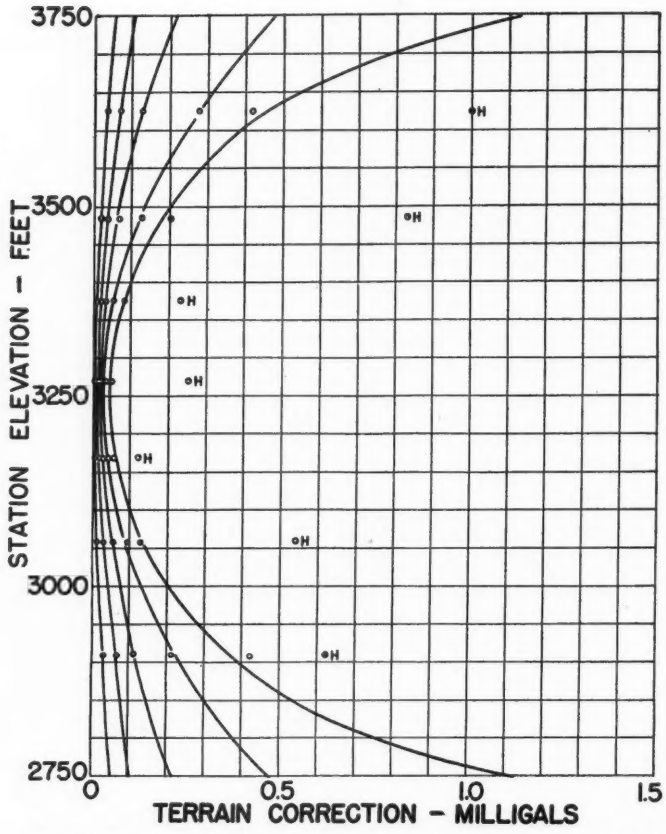

FIG. 1. General case: Total terrain corrections for Zones *M* to *I*. The curve for Zone *H* cannot be approximated by graphing.

mated by the use of the curves, and Zone-*I* total corrections can be estimated by the curves, but could be in error by 0.05 milligal. Corrections for Zone *H* and the remaining inside zones must all be calculated for each individual station.

Terrain corrections become larger and more important in the foothills belts so frequently subjected to gravity-meter surveys. The labor involved in making such corrections can generally be reduced by the use of the same sort of curves as described above. However, the mean elevation across such a belt usually varies quite rapidly from plains on one side to mountains on the other. Therefore, in order to construct and utilize such curves, some sort of an areal-zoning system paralleling the strike must be established across the foothills belt with the mean elevation furnishing the basis for the zoning. Rather than examine a number of elevation profiles across the foothills belt to determine what zoning system should be used, it is suggested that an arbitrary course be embarked upon as follows: Draw a line on the areal map paralleling the strike of the mountains and the foot-

hills and lying at the extreme edge of the plains. Label this line No. 10. A series of parallel lines one mile apart should then be drawn and labeled with successively higher numbers toward the mountains and successively smaller numbers away from the mountains. A few stations as close as possible to each line are then calculated for total terrain effect in each of the outer zones and, from a plot of these data, a family of curves is developed for each zone. Figure 2 shows a typical family of curves for Zone *M* in a hypothetical case.

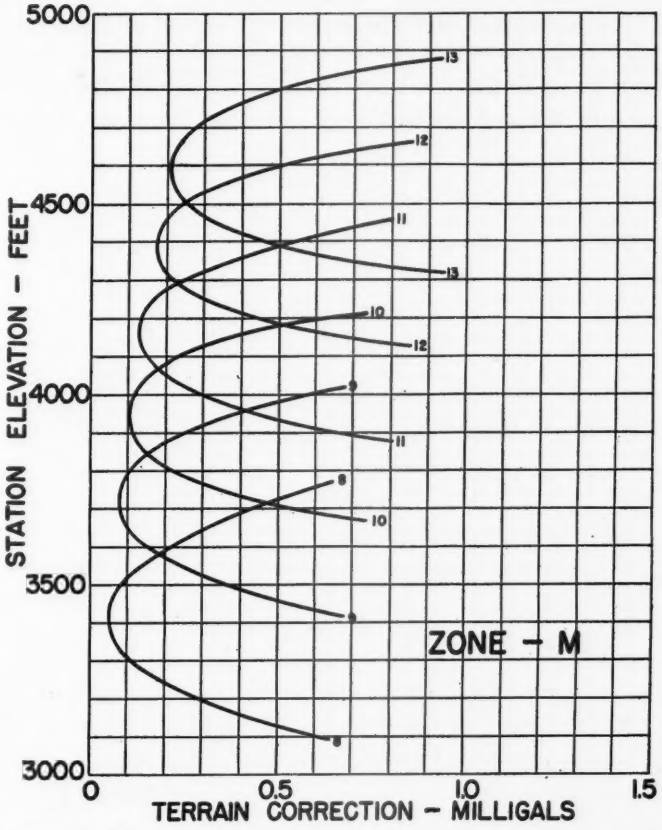

FIG. 2. Special foothills case: Total terrain corrections for Zone *M*. Curves 8 to 13 result from the division of the area into an arbitrary parallel-line zoning pattern. A similar family of curves exists for Zone *L* and for successive inner zones.

By starting with Zone *M*, where the calculated points will track very well, it is possible to detect errors in the original arbitrary zoning system drawn on the areal map. Divergence of these zone lines will be apparent where the foothills belt broadens and they will pinch together where the foothills belt narrows. An exceptionally broad stream valley cutting through the foothills may cause a slight crook in the system of zone lines. Once the correct areal-zoning pattern is

established for Zone *M*, it will also be valid for Zone *L*, *K*, etc., as far as the method is applicable, i.e., until the calculated points fail to track smooth curves. Possibly, it will be found that the particular foothills belt under consideration does not have to be zoned so closely and half of the members of the family of curves can be eliminated, for it is entirely legitimate to interpolate between curves in the same family.

Generally, it is possible to treat the outer three zones (*M*, *L*, and *K*) by means of these curves and sometimes Zone *J* can also be handled. Since the outer four zones contain 64 compartments or 50 per cent of the total compartments to be examined for terrain corrections by Hammer's method, the net saving in time to be expected is 30 to 40 percent when such curves are built up and used. Obviously, the greater the station density in an area, the more time-saving the method becomes.

AN IMPROVED METHOD OF LAND SURVEYING FOR USE IN BRUSH-COVERED AREAS*

KENNETH H. WATERS†

ABSTRACT

The problem of surveying for seismic parties working with the refraction technique in brush-covered areas has been solved by:

(1) Placing the required points rapidly by means of an odograph.

(2) Surveying in points so placed by an adaptation of the horizontal-stadia method, using truck-mounted towers to elevate the instruments above the brush.

Some considerations affecting the accuracy of the method are discussed and the mechanical details of the truck-mounted towers are given.

INTRODUCTION

One of the troublesome problems which have arisen in connection with the correlation method of refraction surveying, as used on the Edwards Plateau and elsewhere, has been the necessity for surveying accurately the distance between the shotpoint and the computing points of the recording spreads. It is generally agreed that an accuracy of 10 feet is required in a distance which may, at times, reach over 30,000 feet. Further, since it is the nature of the seismic method that each surveyed point may serve several times in various capacities (it may be a shotpoint, a recording point for several other shotpoints, or it may be used as a take-off point for further surveys), the surveying of all points within the area must be made to the same degree of accuracy.

It has been standard practice in the past to survey all points by methods involving the use of transits and chains, or by methods involving triangulation from existing U. S. C. & G. S. triangulation stations. Both of these methods have their disadvantages on the Edwards Plateau. Mesquite and cedar brush occurs everywhere on the Plateau, denser in some places than in others, but always thick enough to necessitate the use of two or more brushcutters in addition to the usual survey group of surveyor, head chainman and chainman. Usually a seismic refraction party, unless it is engaged on continuous-line detail work, will require the services of two survey groups to enable recording operations to remain unhampered.

Triangulation offers a solution to the problem of surveying accurately points which already have been located roughly, but it does little to establish points in a given location. In addition, it is limited in its application unless the ground is comparatively flat, the brush is thin and there are one or two small hills to serve as base stations. In the canyon country on the west side of the plateau and in other places where the elevation changes are radical, the difficulties of triangulation are made very great.

* Manuscript received by the Editor January 9, 1948.

† National Geophysical Co., Inc., Dallas, Tex.

During the last few months of 1946, the National Geophysical Company, Inc., had two parties working on the Edwards Plateau as a single unit, and with the three or four survey groups it became evident that the surveying had become too cumbersome. It was at that time that the present solution was worked out.

EVOLUTION OF THE NEW SURVEY METHOD

Primarily the problem may be divided into two parts:

(1) The very rapid placement of points on the land to such a degree of accuracy that they fall within the tolerance demanded by proper geophysical coverage. Practically, this means to within 100 feet or so of the position proposed in planning the work.

(2) The exact surveying of the points so placed to an accuracy demanded by the interpretation technique. Practically, this means the establishment of points to an accuracy of 10 feet or less.

The first of these two parts was solved very rapidly by the employment of the land odograph. This machine, which may be mounted in a jeep or similar vehicle, was developed during the war for use in rapid reconnaissance mapping. It is manufactured by the Monroe Calculating Machine Corporation and also, in a slight variation of form, by the International Business Machines Corporation. The odograph and its operation is fully described by McNish and Tuckerman[1] and its maintenance and some mechanical details are given in the War Department Technical Manual No. 5-9400, but some brief description of its action and capabilities may prove of interest here.

The machine consists of a magnetic compass, fully compensated for the effects of the truck, whose position relative to the direction of travel of the vehicle is followed by an electro-mechanical device. This consists of two photocells actuating two thyratrons which are connected in such a way that the mechanism, operated by a beam of light reflected from a small mirror mounted on the compass card, "hunts" about the true position of the compass "North." The angular amount of hunt is about $\frac{1}{4}$ degree in either direction. The angle between the direction of travel of the vehicle and the magnetic north is communicated to the integrating unit, which subtracts the magnetic declination (pre-set in the machine by the operator) and combines the resulting azimuth with the distance traveled by the vehicle. The distance comes directly from the drive shaft of the truck by an auxiliary speedometer cable. The integrating unit, which lies directly below the plotting table, then multiplies the distance by the sine of the azimuth and communicates the result to the E-W coordinate Veeder counter. Similarly, the product of the distance and the cosine of the azimuth is communicated to and registered by the N-S coordinate counter.

Simultaneously, a pencil is moved over a piece of paper, or map, on the plot-

[1] A. G. McNish and Bryant Tuckerman, "The Vehicular Odograph," *Terrestrial Magnetism and Atmospheric Electricity*, LII (1947), 39–66. Reviewed in *Geophysics*, XII (1947), 464–466.

ting table by an amount which is proportional to the vector sum of the changes in the two coordinates. The scale to which this plotting is done can be varied over a wide range, the largest scale being 2,000 feet to the inch.

The result is a map, to the desired scale, of the route taken by the vehicle. The pencil can be set initially on any desired point. At the same time, the rectangular coordinates of any point can be read off instantly (in miles and decimals of a mile) from the two coordinate Veeder counters.

By placing the plotting table beside the operator, it is very easy for him to guide himself from one point to any other which is marked originally on the map. Use is made of this possibility for setting shotpoints and recording points in the field. The required points and one or two known points are plotted to the desired scale and the resulting map is put on the odograph plotting table. The operator then drives to one of the known points, places the pencil point on that point on the map, starts the odograph mechanism, and by watching the pencil point moving over the plotting table, he guides himself to the first of the unknown points. It is of little importance if obstacles get in his way, since he can go around them and still come back to the desired point.

The accuracy with which points may be set with the odograph depends to some extent on the skill of the operator and on his knowledge of the limitations of his instrument. In dry weather, the odograph can be operated across country, in brush-covered territory like the Edwards Plateau, and preserve an accuracy of about 100 feet in 5 miles of traverse. Of course, care has to be taken to avoid turning the jeep so rapidly that the compass swing cannot be followed or starting the jeep too quickly which temporarily throws the compass out of level. This care, however, soon becomes second nature to a good odograph operator. Originally, it was considered probable that the odograph traverses would have to be closed loops. However, that would not have discovered any scale error in the instrument, nor would it have revealed any constant error in azimuth. Field trials soon showed, moreover, that the system of closed loops was not necessary since the odograph has to be compensated every day against errors of the type which would lead to an unclosed loop.

The order of accuracy given by the odograph is all that is required in laying in shotpoints and recording points. Any variations in spread length or offset distance amounting to only 100 feet or so can be allowed for in the final computations, since the velocity of the seismic wave in the refractor is accurately known. The precise surveying method will reveal the extent of the variations.

Laying in points initially by odograph does, however, contribute vastly to the flexibility of the seismograph crew. Urgent needs may compel the client to revise his program overnight. With the older type of transit surveying, there was then a delay until the new points could be laid in and the drills started. With the odograph, the drill can be on the new point within a few hours of the announcement of the change of program. An additional feature is that since the country can be covered fast—15 to 20 m.p.h. in cross-country work—the odograph surveyor has

time to prepare a map for the remaining units of the field crew which shows trails, fences and gates—a product which saves hours of time for the recording and shooting units. The odograph operator also flags in all spreads and shotpoints and the routes from one point to another.

Once the drill points and recording points have been laid in, the precise surveying has to be done. Clearly, an important improvement would be made if the surveying could be done over the top of the brush, instead of by cutting through it. This would eliminate two or more brushcutters for each survey group—a not inconsiderable saving in labor costs—but at the same time it would introduce the difficulty of distance measurement between two points. The measurement of angles could be made with standard surveying instruments mounted on towers which, for mobility, would be truck mounted.

An electronic method of measuring distance would have been ideal, but none was available at that time which would give sufficient accuracy. A review of other methods of measuring distance brought to mind the stadia method which, however, in its usually used form would have been far too inaccurate. It gave sufficient promise, however, that steps were taken to refine it.

First of all, as part of the refinement, the stadia rod was increased in length and turned into a horizontal position to avoid, as far as possible, the effects of differential atmospheric refraction. Then, instead of relying on the intercept read on the rod by two stadia hairs, the process was reversed. The distance was kept constant and the angle subtended at the instrument was accurately measured.

Provided, then, that the distance could be measured with sufficient accuracy by this method, it was planned to survey by a traverse method, all measurements made being angles. The progress of such a survey is illustrated in Figure 1. For

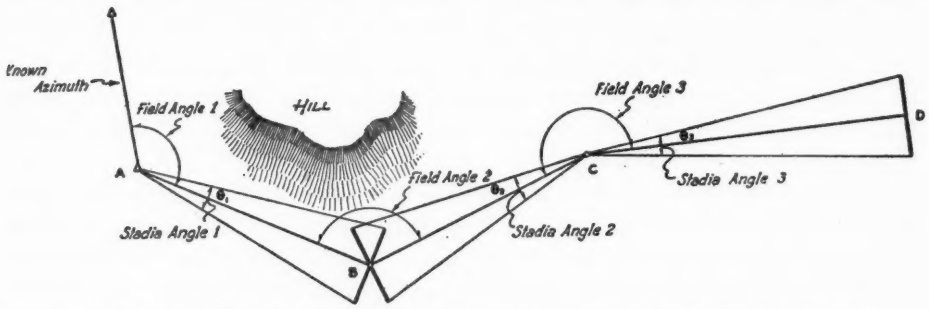

FIG. 1. Schematic diagram of the progress of a survey traverse using the horizontal-stadia method.

ease of illustration, the length of the stadia arms is exaggerated compared with the distances measured. In all positions where distance is to be measured, the stadia arm is set at right angles to the line of sight from the other instrument to the center of the arm, at which point is mounted the second instrument. Arrangement is also made to level the stadia arm.

The first tower is set up over a point whose coordinates are accurately known

and from which a known azimuth can be obtained. The most convenient point for this purpose is a U. S. C. & G. S. triangulation station, which normally has an azimuth station associated with it. However, any other known point will do, since by taking a backsight to another known point, or by making a Polaris observation, the starting azimuth can be found. In the meantime, the second tower has proceeded to a point B, which may be in any location convenient to the traverse being made. For example, in the case illustrated, the hill would be in the way of a straight line traverse between A and D. At point B the second tower is set up, the arm levelled and set at right angles to the line of sight from A. The observer at A then measures two angles, the field angle between his known azimuth and the line to the center of the arm at B, and also the angle subtended by the arm at A. Simple arithmetic then gives the azimuth of the line AB and the length of the line AB is given by the formula

$$AB = L/2 \cot \theta/2;$$

or, provided that θ is small

$$AB \cong L/\sin \theta \cong L/\tan \theta \cong L/\theta,$$

where L is the stadia length and θ is the angle subtended (in radians).

The first tower then moves to position C and the observer on the second tower, having taken a reading on the position A, measures the field angle 2. This enables the azimuth of BC to be obtained and a further stadia-angle measurement at C back to B, with the stadia arm readjusted at right angles to the new line of sight, gives the distance BC. The traverse then proceeds in leap-frog pattern until the desired point is reached.

CONSIDERATIONS OF ACCURACY AND INSTRUMENTATION

It is apparent that if the traverse has to be run at a reasonable speed, the distances measured must be as large as possible consistent with the accuracy desired. This optimum distance will increase if the length of the stadia arm is increased, but mechanical difficulties become very great for arms longer than 40 feet. The arms have to fold down against the tower and the tower has to be lowered to a horizontal position while moving. Thus, with the arm made up of two parts, one on either side of the tower, the tower will have to be about 20 feet high. This was found to be a manageable height.

With the best commercially available theodolite, the smallest angle which can be measured consistently is about one second of arc; it is conceivable that this accuracy could be increased, but, as will be seen later, other considerations limit the usefulness of accuracy beyond this point.

An instrument of this accuracy will then enable a distance of 3,000 feet to be measured to an accuracy of about $1\frac{1}{2}$ feet, provided that there are no perturbations from outside influences. The effect of an error in measuring the angle may be found as follows:

Let an error $\delta\theta$ be made in measuring the stadia angle θ, the distance measured

be D, and the stadia length be L. Then, for small angles, it has been shown that

$$D \cong L/\theta.$$

Differentiating to get the error in distance δD as a function of the angular error $\delta\theta$, it may be seen that

$$\delta D = -L/\theta^2 \cdot \delta\theta,$$

and, substituting for θ,

$$\delta D = -D^2/L \cdot \delta\theta.$$

Thus, for all practical distances for which θ is small, the effect of a given error in the stadia angle will be proportional to the square of the distance measured. This puts an effective limit on the distances which can be measured with the required degree of accuracy. In practice, it has been found that occasional distances of 4,000 feet can be measured without impairing the overall accuracy of 10 feet in 30,000, which is required, but it is best to keep the distances down to 3,000 feet if it is at all possible.

Now, if it is possible to measure 3,000 feet to an accuracy of $1\frac{1}{2}$ feet, the stadia length must be known to one part in 2,000 and must stay constant within those limits. That means that, with a stadia length of 40 feet, the arm length must stay constant to within $\frac{1}{4}$ inch and must be observable to that accuracy. This proved to be possible after some experimentation on the fiducial marks to be observed. With the first stadia arm of wood there was no difficulty with temperature effects (coefficient of expansion 3×10^{-6}), but with the newer arm of aluminum (coefficient of expansion 24×10^{-6}), some care was necessary in calibrating the equipment, that is, to obtain the stadia length. A 25°C. change in temperature will change the length of the arm by 0.29 inches and it was necessary to choose a mean operating temperature for making the calibration. In fact this stadia length should be measured from time to time, always by the observer who makes the field readings, to ensure that the stadia length has not changed by accidental knocks, by fatigue of the supports, etc. Some seasonal effects will be noticed in this length.

Levelling and setting the arms at right angles to the line of sight of the observer are important, but no very great accuracy is necessary in these settings. If they are set to within one degree, an accuracy of 1 part in 5,000 is maintained. This is because the effect is dependent on the sine of the angle between the arms and the line of sight of the observer, and in the vicinity of 90° the sine changes very slowly with change of angle. The adjustments are therefore made by using a pre-set peepsight for perpendicularity and an insensitive bubble for level.

The fiducial marks on the arms are important. Except in very rare cases, it is impossible to see clearly enough at 3,000 feet to set the cross hairs on a line dividing the target into two areas of different color. The contrast is not sufficient to

show clearly through the heat waves, or if it can be seen, the strain on the observer to make these coincidences continually is too great. After some experimentation, single-filament, 50-candlepower, 6-volt lamps have been selected as being the most suitable. The coiled filaments are about $\frac{1}{4}$-inch long and 1/32-inch wide. It is desirable also to prevent stray reflections from affecting the result by shielding the lamp with a brass shield in which a $\frac{1}{4}$-inch diameter hole has been punched to serve as a diaphragm.

A subjective effect of the observer has caused some trouble. It was found that the accuracy of setting the cross hairs on the filament of the lamp is affected by the contrast between the brightness of the filament and the background. While the filament at full brightness is necessary in strong sunlight with the sky as a background, the same brightness of the filament on a dull day causes two or three times the error of an individual setting. In this case it was found that a green filter (Wratten No. 11) improved the accuracy of setting, and, at distances less than 2,000 feet, it was found necessary to use a neutral density filter in addition.

In practical surveying, however, it is much too cumbersome to change filters continually, and the present usage is to vary the voltage across the filament with a variable resistor.

The instruments used on both towers are Wild T-2 theodolites. These are beautifully made instruments, of Swiss manufacture, incorporating a novel optical system whereby all angles are read through one microscope mounted alongside the telescope. A more complete description appears in textbooks on surveying.[2]

DETAILS OF THE MECHANICAL DESIGN OF THE TOWERS

Due to the accuracy with which the angles are to be read in this surveying method, the tower design is complicated somewhat by the necessity of mounting the instrument on a tripod, which must, for all practical purposes, be separate from the tower on which the observer stands. The tower must be made in such a way that, when it is lowered to the horizontal position for moving, the overall height is a minimum so that the tower truck may pass through gates having a strain wire across the top. In addition, the width of the truck must be kept to a minimum to enable it to pass through many of the narrow gates encountered in the field.

The tower was installed on the front end of the truck since this makes for a more compact design and, in addition, allows the driver to approach more closely to a given spot for raising the tower. The tower is raised from the horizontal position by the front-end winch, which is powered by the power take-off on a Dodge Power Wagon. A photograph of the tower in the down position is given in Figure 2. For driving on the highway, the feet, on which the tower is supported while in a vertical position, are swung out of the line of vision of the driver. For driving in the field, this increases the overall height too much and they are al-

[2] Breed and Hosmer, *Surveying*, II (Sixth Ed.; John Wiley & Son, 1947.)

lowed to hang vertically. When the tower is raised, the feet continue to hang freely from their pivot until the tower is nearly vertical, when the shoes (made of 6-inch channel iron) touch the ground. By continued action of the winch, the tower is raised to a vertical position, the front end of the truck being automatically jacked off the ground so that all the weight is taken on the feet. This position is illustrated by the photograph in Figure 3.

FIG. 2. Photograph of one of the truck-mounted surveying towers lowered and in position for moving.

All three legs of the center tripod on which the instrument is mounted rest on the ground. The two fixed legs are welded to the pipe which forms the pivot for the two feet and, when the weight is on the feet, are thus essentially on the ground. The third leg is pivoted to the other two just below the observer's platform so that it can extend forward from the front of the truck. Before the third leg is extended forward, the pipe on which the instrument rests is constrained to rest against the front end of an oval hole cut in the floor of the platform. The third leg is then extended, and the pipe is forced into the middle of the hole in the floor by pushing the base of the third leg toward the truck. The effect of this is to force the base of the third leg into the ground and thus make the instrument tripod quite steady.

In this way, the coupling between the movement of the tower and the movement of the tripod is reduced to a minimum. To illustrate that this method is effective, it may be noted that when a man of weight 200 pounds moves into any position around the platform, the maximum angular change of the instrument was found to be four seconds of arc.

With respect to angular motion in a vertical plane the tower is a little stiffer,

amounting to 27 seconds for the same stress change on the tower. However, this is unimportant since all vertical angles are read against a level bubble on the instrument and changes in the angle of the vertical axis of the instrument are compensated.

Fortunately, the stadia angles, which have to be read to an accuracy of at

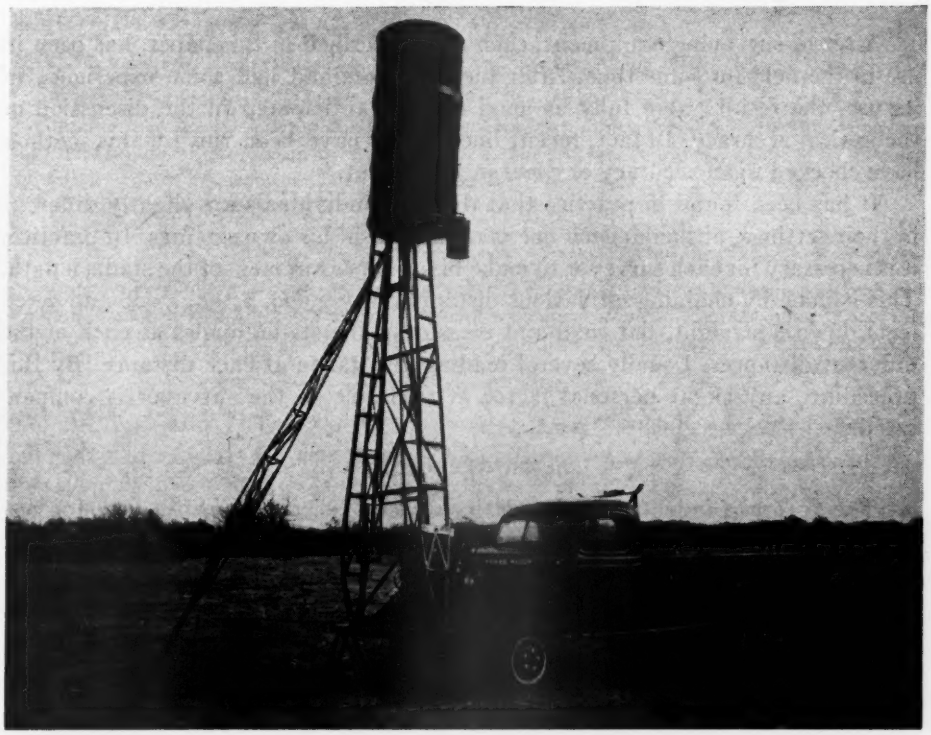

FIG. 3. Photograph of one of the truck-mounted surveying towers elevated and the inner tripod in position for taking readings with the theodolite.

least one second, can all be read without change in position of the observer (the usual stadia angle measured is approximately 45 minutes).

The tower carrying the stadia arms employs the same principles of construction, but in addition has to provide a method for carrying the arms, levelling them and rotating them about a central vertical axis. The base of a gun turret from War Surplus proved to be an ideal method of rotating the arms. It was attached to the top of the observer's turret. The arms are hinged to the ends of a piece of $3\frac{1}{2}$-inch pipe about 3 feet long, in the center of which is a loop, through which passes the pipe carrying the instrument. The arms themselves are made from extruded aluminum masts, tapered on one end and of streamline cross section.

They are 18 feet long and were designed primarily for the masts of small sailing boats. Each 18-foot length weighs about 18 pounds. This type of extruded section without the tapered end was also used in this tower for the legs of the tripod. Some stiffening was necessary in the direction of the minor axis of the section before the tripod possessed the necessary rigidity.

FIELD RESULTS

A set of surveying equipment, such as is described in this paper, has been in use in the field for some time. After the surveyors had had some experience in its use, the results were fully as good as were anticipated in the discussion of theoretical accuracy. In fact, recent lines which have been run by this method have checked to an accuracy of 5 feet in 30,000 feet.

It has been found in practice that different individuals are slightly different in their settings, although each one is consistent in his own settings. In practice, it is necessary for each surveyor to make his own measurement of the stadia length. This is done by chaining off various distances (say 2,000, 2,500, 3,000 and 3,500 feet) down a straight, flat road and measuring the stadia angles at each of the different distances. Usually several readings are taken at each distance. By this procedure, any slight personal factor attributable to the surveyor is compensated.

ACKNOWLEDGMENTS

The author is indebted to the National Geophysical Company, Inc., for permission to publish this paper, and to several of its members, both past and present, who have contributed greatly to the success of the method.

PATENTS*

12—ACOUSTIC MEASUREMENTS

U. S. No. 2,429,229. W. Koenig, Jr. Iss. 10/21/47. App. 4/4/45. Assign. Bell Telephone Laboratories, Inc.

Analysis and Representation of Complex Waves. A system for the spectral analysis of speech waves, the sound being first recorded on an endless magnetic tape and then repeatedly analysed by modulating with a variable frequency oscillator, passing through a pair of slightly overlapping opposed band-pass filters and recording in the form of frequency contours.

U. S. No. 2,429,236. R. K. Potter. Iss. 10/21/47. App. 4/5/45. Assign. Bell Telephone Laboratories, Inc.

Analysis and Representation of Complex Waves. A system for the spectral analysis of speech waves, the sound being first recorded on an endless magnetic tape and then repeatedly analysed by modulating with a variable frequency oscillator, passing through a band-pass filter and rectifier and recording in the form of intensity contours.

U. S. No. 2,430,013. C. W. Hansell. Iss. 11/4/47. App. 6/10/42. Assign. Radio Corp. of America.

Impedance Matching Means for Mechanical Waves. A means of transmitting waves from one medium to another without reflection by interposing a medium having a wave impedance which is the geometric mean of the other two and whose thickness is an odd number of quarter wave lengths.

16—AIRPLANE FLIGHT INSTRUMENTS

U. S. No. 2,428,424. V. D. Landon. Iss. 10/7/47. App. 5/30/45. Assign. Radio Corp. of America.

Pulse-Echo Altimeter. A radio distance determining system in which a super-regenerative oscillator is used both as transmitter and receiver, the transmitter having a cyclical voltage applied to it to vary its blocking rate and the received pulses causing momentary locking-in when the reflection time is reached.

U. S. No. 2,431,344. A. H. Reeves. Iss. 11/25/47. App. 5/20/40 and 2/22/44. Assign. International Standard Electric Corp.

Determining Distance by Electromagnetic Waves. A radio ranging system in which a super-regenerative receiver has periodic short pulses applied to cause oscillation as a transmitter and receives the reflected pulses between transmitted pulses.

48—CASING PERFORATOR

U. S. No. 2,429,240. M. Schlumberger. Iss. 10/21/47. App. 2/2/39, 1/23/40 and 7/23/41. Vested in Attorney General of U. S.

Well Casing Perforator. A perforating gun having longitudinal powder chambers and transverse gun bores and a complete ignition path extending through the gun.

U. S. No. 2,433,231. P. W. Martin. Iss. 12/23/47. App. 10/29/45.

Externally Fired Perforating Gun. A casing perforating gun whose gun barrels are blind holes, the gun having a spirally-wound external powder train detonation of which causes the bullet to compress and detonate the propelling charge.

108—ECHO SOUNDING

U. S. No. 2,433,332. H. Benioff. Iss. 12/30/47. App. 10/22/41. Assign. Submarine Signal Co.

System for Locating Obstacles. A multi-channel compressional-wave harbor-protection system in

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation.

which impulses are sent out and the reflection picked up by receivers directed to cover various parts of the area, each receiver being connected to an indicator moved across the recording chart proportional to the speed of sound in water and an indication made when the reflection is received.

U. S. No. 2,433,361. B. M. Harrison. Iss. 12/30/47. App. 1/20/40. Assign. Submarine Signal Co.

Method and Apparatus for Echo Ranging. A supersonic echo distance-measuring system which transmits a signal whose frequency is continuously varied at a high audio frequency and the echo used to produce an audio signal which operates a timed indicator.

U. S. No. 2,433,385. O. R. Miller. Iss. 12/30/47. App. 11/5/42. Assign. Bell Telephone Laboratories, Inc.

Submarine Locating System. An echo distance-measuring system in which a standard frequency wave train is transmitted and the pulses counted, the length of the train being adjusted so that the transmitted train is stopped just before the echo is received.

116—ELECTRIC LOGGING

U. S. No. 2,433,746. H. G. Doll. Iss. 12/30/47. App. 6/13/42. Assign. Schlumberger Well Surveying Corp.

Method and Apparatus for Investigating Earth Formations Traversed by Boreholes. A method of determining permeability of formations by generating opposite the formation a fluctuating pressure to generate a fluctuating electrofiltration potential whose a.-c. component may be distinguished from steady self-potential.

132—ELECTROMAGNETIC PROSPECTING

U. S. No. 2,428,360. E. N. Dingley, Jr. Iss. 10/7/47. App. 1/16/45.

Electrical Guidance System for Surface Vessels. A system for guiding a ship along a narrow channel by energizing a submerged cable with a.c. and picking up the field with horizontal and vertical coils on the ship.

136—EXPLOSIVE

U. S. No. 2,428,884. E. K. Lefren. Iss. 10/14/47. App. 4/17/42. Assign. Hercules Powder Co.

Electric Blasting Cap. A detonator whose plug carries rubber fins which seal against the inside of the metal shell to prevent entrance of moisture.

U. S. No. 2,429,079. W. F. Smith. Iss. 10/14/47. App. 6/30/43. Assign. Hercules Powder Co.

Connecting Means for Explosive Cartridges. A dynamite cartridge having thread lugs and furnished with an internally threaded sleeve which may be partially unscrewed to permit engaging the adjacent cartridge.

U. S. No. 2,429,490. G. H. Scherrer. Iss. 10/21/47. App. 10/12/45. Assign. Hercules Powder Co.

Detonator. An electric detonator having an ignition charge which ignites a heating charge which heats a heat-conducting disk in contact with the detonating charge.

U. S. No. 2,431,683. A. M. Biggar. Iss. 12/2/47. App. 2/23/45. Assign. U.S.A.

Detonator Tester. Apparatus for testing heat-sensitive detonators by exposing them to a flash of flame and backing them up with a soft lead disc which will be pierced if a high order detonation results.

U. S. No. 2,431,871. D. D. Huyett. Iss. 12/2/47. App. 10/26/40. Assign. Atlas Powder Co.

Electric Explosion Initiator. A blasting cap made by inserting leg wires and ignition element into a thermoplastic shell containing the explosive and then swaging the top closed by means of heated discs.

U. S. No. 2,433,417. C. D. Bitting and R. W. Lawrence. Iss. 12/30/47. App. 10/5/43. Assign. Hercules Powder Co.

Blasting Explosive. A gelatin type of seismograph or well shooting explosive containing corn meal whose cell walls have been stiffened with a resin to improve the performance of the explosive under prolonged hydrostatic pressure.

U. S. No. 2,433,543. J. L. Bisch. Iss. 10/30/47. App. 1/5/44. Assign. Atlas Powder Co.

Means for Positioning Explosives in Boreholes. A spring wire bent into the form of a tong with a resilient loop at the top and with one or more barbs or hooks on the legs for catching the cartridge.

140—FLAW DETECTOR

U. S. No. 2,428,471. J. G. Pruitt and E. R. Oberdorf. Iss. 10/7/47. App. 2/8/43. Assign. Magnaflux Corp.

Magnetic Testing Method and Apparatus. A magnetic flaw-detecting apparatus having tanks containing liquid with suspended iron powder, one tank having a coil for testing for transverse flaws, one tank having a coil for testing for longitudinal flaws and a demagnetizing tank for removing the iron powder after testing.

U. S. No. 2,429,336. T. Zuschlag. Iss. 10/21/47. App. 11/19/42. Assign. Magnetic Analysis Corp.

Electromagnetic Testing. A magnetic testing method for rods and tubes in which the specimen is passed through a coil having a.-c.excitation and the effect picked up with one or more coils connected to shock-excite a high frequency resonant filter circuit.

U. S. No. 2,430,167. R. L. Fitch. Iss. 11/4/47. App. 7/5/43.

Automatic Magnetic Inspection Apparatus. A flaw detector in which the article is sprayed with a liquid inspection medium and the magnetizing current turned on automatically as the flow of inspection medium is turned off.

U. S. No. 2,431,233. W. S. Erwin. Iss. 11/18/47. App. 4/21/44. Assign. General Motors Corp.

Supersonic Measuring Means. A supersonic inspection system using a piezoelectric crystal to drive the sample at resonance and electrically measuring the mechanical loading on the crystal.

U. S. No. 2,431,234. G. M. Rassweiler and W. S. Erwin. Iss. 11/18/47. App. 12/4/44. Assign. General Motors Corp.

Automatic Sonic Measuring Means. A supersonic inspection system in which a cyclically varying supersonic oscillation is impressed on the sample and the output of the oscillator observed with a c.-r. oscilloscope.

U. S. No. 2,431,862. B. Carlin. Iss. 12/2/47. App. 3/26/46. Assign. Sperry Products, Inc.

Means for Supersonic Inspection. A continuous-wave supersonic inspection apparatus in which standing waves are eliminated by immersing the sample in a fluid medium excited by several transmitters arranged in out-of-phase relation.

U. S. No. 2,432,786. A. J. Newman. Iss. 12/16/47. App. 11/20/43. Assign. Curtiss-Wright Corp.

Machine for Testing and Marking Parts Magnetically. An automatic magnetic testing and flaw marking machine which coats the articles with a suspension of iron oxide and passes a current through the article so as to produce a concentration of iron oxide at the flaws.

152—FLUORESCENCE LOGGING

U. S. No. 2,431,487. D. H. Larsen. Iss. 11/25/47. App. 6/22/42. Assign. National Lead Co.

Oil Detection in Drilling Muds. A method of detecting oil in drilling mud by treating the mud with a mutual solvent for oil and water and subjecting to fluorescence excitation.

160—GALVANOMETER

U. S. No. 2,430,154. J. G. Woodward. Iss. 11/4/47. App. 6/26/43. Assign. Radio Corp. of America.

Oscillograph Timing Circuit. A circuit for obtaining a synchronized sweep on a c.-r. tube.

168—GAS ANALYSIS

U. S. No. 2,431,019. R. B. Barnes. Iss. 11/18/47. App. 8/29/44. Assign. American Cyanamid Co.

Multicomponent-Gas Analyzer. An infrared absorption analyzer in which a broad band of infrared radiation is passed through the sample and then through a succession of detecting cells containing components which have no overlapping absorption bands in the radiation band used.

180—GRAVIMETER

U. S. No. 2,432,875. E. Flint. Iss. 12/16/47. App. 9/1/42. Assign. Bausch & Lomb Optical Co.

Level Indicating Device. A level indicator having two immiscible liquids and a body floating on the interface between them, the body being kept out of contact with the wall by a concave meniscus of the heavier liquid.

196—INFRARED MEASUREMENTS

U. S. No. 2,431,019. R. B. Barnes. Iss. 11/18/47. App. 8/29/44. Assign. American Cyanamid Co.

Multicomponent-Gas Analyzer. An infrared absorption analyzer in which a broad band of infrared radiation is passed through the sample and then through a succession of detecting cells containing components which have no overlapping absorption bands in the radiation band used.

224—MAGNETIC RECORDER

U. S. No. 2,428,449. M. Camras. Iss. 10/7/47. App. 3/2/45. Assign. Armour Research Foundation.

Magnetic Recording Head. A magnetic recording head in which the tape first passes a permanent magnet which saturates the medium and then an oppositely directed weaker magnet which partially demagnetizes the medium while it is under the influence of the recording coil.

U. S. No. 2,428,701. S. D. Eilenberger. Iss. 10/7/47. App. 2/2/45. Assign. Wolgen Co.

Magnetic Head. A magnetic recording and reproducing head for spirally grooved disc records in which the record is made on the lands between the grooves.

U. S. No. 2,429,703. H. A. Vagtborg, M. Camras and R. E. Zenner. Iss. 10/28/47. App. 12/26/42. Assign. Armour Research Foundation.

Magnetic Recording Device. A portable self-energized magnetic recorder using a spring motor and carbon microphone connected through a battery and transformer to the recording head.

U. S. No. 2,429,792. S. J. Begun. Iss. 10/28/47. App. 4/7/43. Assign. The Brush Development Co.

Magnetic Recording-Reproducing Means and System. An erasing head for a magnetic recorder having a.-c. carrying coils on each side of a recording medium with poles at right angles so as to produce a diffuse a.-c. field.

U. S. No. 2,430,538. R. M. Somers. Iss. 11/11/47. App. 6/14/44. Assign. Thomas A. Edison, Inc.

Telegraphone. A multi-lane magnetic-tape recorder in which the driving motor is automatically reversed when the end of the tape is reached and connection is made to the recording head for the adjacent lane.

U. S. No. 2,431,540. M. Camras. Iss. 11/25/47. App. 3/2/45. Assign. Armour Research Foundation.

Magnetic Recording Head. A magnetic recording or reproducing head of the open slot type for

longitudinal magnetization of a wire or tape and having an energizing winding which passes through a central hole and elongated slots in the pole pieces.

U. S. No. 2,431,541. M. Camras. Iss. 11/25/46. App. 5/31/45. Assign. Armour Research Foundation.

Magnetic Recording Head. A magnetic recording or reproducing head of the open slot type for longitudinal magnetization of a wire or tape and having its energizing coil wound through a central hole and notches in the pole pieces which are afterward filled with non-magnetic blocks.

U. S. No. 2,431,739. S. D. Eilenberger. Iss. 12/2/47. App. 12/4/46. Assign. Chicago Coin Machine Co.

Magnetic Sound Recording. A cylindrically-shaped magnetic record in which the cylinder has two spiral wires partially embedded in it, one wire being of high retentivity for sound track and the other wire being of low retentivity to act as a shield between adjacent tracks.

U. S. No. 2,432,162. C. B. Jones. Iss. 12/9/47. App. 3/11/44. Assign. The Brush Development Co.

Removable Pole Pieces for Magnetic Recording and Reproducing Heads. A magnetic recorder head in which the wire passes through the energizing coil and longitudinally across the face of the pole pieces which are mounted on a bar of non-magnetic material inserted into the coil.

U. S. No. 2,433,207. S. D. Eilenberger. Iss. 12/23/47. App. 5/19/45. Assign. Chicago Coin Machine Co.

Rectilinear Pole Piece for Magnetic Sound Heads. A magnetic recording head for cylindrical records and having a T-shaped pole piece whose width is equal to the wire diameter and length equal to the wave length of the lowest frequency desired, recording being effected from the trailing edge of the pole piece.

228—MAGNETIC TESTING

U. S. No. 2,428,471 J. G. Pruitt and E. R. Oberdorf. Iss. 10/7/47. App. 2/8/43. Assign. Magnaflux Corp.

Magnetic Testing Method and Apparatus. A magnetic flaw detecting apparatus having tanks containing liquid with suspended iron powder, one tank having a coil for testing for transverse flaws, one tank having a coil testing for longitudinal flaws and a demagnetizing tank for removing the iron powder after testing.

U. S. No. 2,429,336. T. Zuschlag. Iss. 10/21/47. App. 11/19/42. Assign. Magnetic Analysis Corp.

Electromagnetic Testing. A magnetic testing method for rods and tubes in which the specimen is passed through a coil having a.-c. excitation and the effect picked up with one or more coils connected to shock-excite a high frequency resonant filter circuit.

U. S. No. 2,432,811. J. A. Sams. Iss. 12/16/47. App. 10/14/44. Assign. General Electric Co.

Magnetic Testing Device. A portable gauge for measuring the flux in a magnetic material having a coil on a closed high-permeability magnetic core which may be placed against the material, the change in reactance of the coil being indicated.

232—MAGNETOMETER

U. S. No. 2,431,319. W. B. Ellwood. Iss. 11/25/47. App. 2/9/43.

Magnetic Firing Device. A magnetic detector having two bar magnets whose mid points are bridged by a magnetic rod interrupted by magnetic contacts which close an electric circuit when the symmetry of the bridge is disturbed.

U. S. No. 2,432,514. M. C. Depp and C. F. Fragola. Iss. 12/16/47. App. 3/27/45. Assign. Sperry Gyroscope Co., Inc.

Adjustable Flux Valve. A flux valve having two adjacent separately excited parallel cores slightly displaced from each other in the longitudinal direction surrounded by a single pickup coil which may be longitudinally adjusted so that components of fundamental frequency are balanced out.

236—MASS SPECTROMETRY

U. S. No. 2,431,335. R. V. Langmuir. Iss. 11/25/47. App. 7/15/43. Assign. Consolidated Engineering Corp.

Direct-Current Amplifier. A negative-feedback d.-c. amplifier for a mass spectrometer having a type 38 tube in its input stage operated at low voltage and at an amplification factor greater than unity and with the tube and its grid resistor enclosed in an evacuated shielded envelope.

U. S. No. 2,431,355. H. W. Washburn. Iss. 11/25/47. App. 7/3/43. Assign. Consolidated Engineering Corp.

Evacuating System for Mass Spectrometry. A system for preventing contamination of a mass spectrometer by using a series of vapor traps between the spectrometer and the pump, with the coldest trap nearest to the spectrometer, and a magnetically operated totally enclosed valve between the trap and the spectrometer.

244—MICROPHONE

U. S. No. 2,432,083. R. Black, Jr., F. F. Romanow and O. A. Shann. Iss. 12/9/47. App. 12/8/42. Assign. Bell Telephone Laboratories, Inc.

Hydrophone. A hydrophone having an inertia-type transducer mounted on the flat side of a D-shaped frame which slides into a thin-walled container coated on the outside with a thin layer of rubber.

U. S. No. 2,432,424. J. J. Hyland and W. J. Muldoon. Iss. 12/9/47. App. 8/21/44. Assign. Control Instrument Co., Inc.

Electromagnetic Sound-Translating Device. A voice-powered telephone unit in which the pole pieces support the motor assembly and prevent lateral displacement of the armature and voice coil.

U. S. No. 2,433,383. W. P. Mason and H. J. McSkimin. Iss. 12/30/47. App. 6/24/44. Assign. Bell Telephone Laboratories, Inc.

Crystal Microphone. A Rochelle-salt piezoelectric hydrophone using 45° Y-cut crystals mounted between two diaphragms for longitudinal vibration and having porous insulating spacers between the crystals and the diaphragms to reduce distributed capacity.

252—MUD LOGGING

U. S. No. 2,431,487. D. H. Larsen. Iss. 11/25/47. App. 6/22/42. Assign. National Lead Co.

Oil Detection in Drilling Muds. A method of detecting oil in drilling mud by treating the mud with a mutual solvent for oil and water and subjecting to fluorescence excitation.

276—PERMEABILITY TESTING

U. S. No. 2,429,577. R. W. French, Jr. Iss. 10/21/47. App. 11/22/44. Assign. Continental Oil Co.

Method for Determining Fluid Conductance of Earth Layers. A method of determining the permeability of a stratum by impressing a radioactive fluid on the formation in one well and observing the increase in radioactivity of the stratum in adjacent wells.

U. S. No. 2,433,746. H. G. Doll. Iss. 12/30/47. App. 6/13/42. Assign. Schlumberger Well Surveying Corp.

Method and Apparatus for Investigating Earth Formations Traversed by Boreholes. A method of determining permeability of formations by generating opposite the formation a fluctuating pressure to generate a fluctuating electrofiltration potential whose a-c component may be distinguished from steady self-potential.

288—PRESSURE GAUGE

U. S. No. 2,431,006. C. M. Wolfe. Iss. 11/18/47. App. 6/11/46. Assign. Aerojet Engineering Corp.

Pressure Operated Resistor. An engine cylinder pressure gauge in which the pressure forces a metal diaphragm into an increasing area of contact with a thin strip of conducting coating on a concave ceramic surface and short circuits a varying portion of the strip.

304—RADIOACTIVITY LOGGING

U. S. No. 2,429,577. R. W. French, Jr. Iss. 10/21/47. App. 11/22/44. Assign. Continental Oil Co.

Method for Determining Fluid Conductance of Earth Layers. A method of determining the permeability of a stratum by impressing a radioactive fluid on the formation in one well and observing the increase in radioactivity of the stratum in adjacent wells.

U. S. No. 2,433,554. G. Herzog. Iss. 12/30/47. App. 10/27/42. Assign. The Texas Co.

Well Logging Apparatus. A radioactivity logging apparatus having an ionization chamber and a high output resistance whose temperature is controlled by a constant temperature regulator.

312—RADIO NAVIGATION

U. S. No. 2,428,427. A. V. Loughren. Iss. 10/7/47. App. 9/15/44. Assign. Hazeltine Research, Inc.

Position-Indicating Device. A radio plan position indicator on which the distance and direction to a fixed station is indicated and having a map superimposed on the c.-r. tube screen, the map being automatically shifted when the operator shifts to another fixed station.

316—RADIO RANGING

U. S. No. 2,429,623. W. F. Hoisington. Iss. 10/28/47. App. 9/14/42. Assign. Federal Telephone and Radio Corp.

Pulse Distance Measuring System. A radio pulse echo system in which a linearly increasing sweep voltage is generated at transmission and used as a debiasing voltage on a blocked amplifier in the receiver circuit, the echo signal supplying the balance of the required debiasing voltage to unblock the amplifier.

U. S. No. 2,430,283. D. W. Epstein. Iss. 11/4/47. App. 4/13/45. Assign. Radio Corp. of America.

Radio Distance and Direction Recorder. A pulse-echo radar system in which an optical system projects the c.-r. tube image onto an Orthicon tube whose screen is scanned and recorded in polar coordinates by a printing recorder.

U. S. No. 2,431,344. A. H. Reeves. Iss. 11/25/47. App. 5/20/40 and 2/22/44. Assign. International Standard Electric Corp.

Determining Distance by Electromagnetic Waves. A radio ranging system in which a supergenerative receiver has periodic short pulses applied to cause oscillation as a transmitter and receives the reflected pulses between transmitted pulses.

324—RECORDER

U. S. No. 2,428,369. E. W. Kammer. Iss. 10/7/47. App. 12/14/45.

Optical Time-Base Generator. A system for obtaining on a photographic record tape a zero line having bright spots at the time interval marks.

U. S. No. 2,428,778. J. Bolsey. Iss. 10/14/47. App. 1/15/44.

Photoelectric Reproducer for Plural Consecutive Sound Tracks. A system of sound track recording in which a wide strip with a number of tracks is repeatedly run through the apparatus in successively opposite directions.

U. S. No. 2,430,780. H. O. Peterson. Iss. 11/11/47. App. 12/19/42. Assign. Radio Corp. of America.

Recording Instrument. A device for recording readings of a pointer-type meter by having the pointer intercept a light beam from a lamp to a revolving scanning mirror and photocell whose impulse is recorded on a drum revolving in synchronism with the scanning mirror.

U. S. No. 2,432,303. R. S. Fox. Iss. 12/9/47. App. 12/31/45.

Continuous Angularly Movable Light Beam Recorder. A light beam recorder which uses electro-sensitive paper and in which the light beam traverses a drum with selenium segments which are made conducting so that current will pass to the paper and make a mark.

U. S. No. 2,433,382. W. A. Marrison. Iss. 12/30/47. App. 9/11/44. Assign. Bell Telephone Laboratories, Inc.

Recorder System with Electromagnetically Attracted Electric Stylus. A system for recording with a stylus on electro-sensitive paper, the stylus being normally out of contact with the paper and brought into contact with the paper by an interrupted current in a magnet behind the paper.

344—SEISMOGRAPH AMPLIFIER

U. S. No. 2,431,306. P. K. Chatterjea and C. T. Scully. Iss. 11/25/47. App. 7/9/42 and 5/8/43. Assign. International Standard Electric Corp.

Thermionic Amplifier. An amplifier having a thermistor connected between grid and cathode to vary the grid bias in order to compensate for variation in supply voltage.

U. S. No. 2,431,307. P. K. Chatterjea and C. T. Scully. Iss. 11/25/47. App. 7/23/42 and 6/22/43. Assign. International Standard Electric Corp.

Thermionic Valve Amplifier. An amplifier for low frequency or d.c. and having a thermistor as coupling element between stages.

356—SEISMOGRAPH MIXING

U. S. No. 2,431,600. A. Wolf. Iss. 11/25/47. App. 4/20/43. Assign. Texaco Development Corp.

Seismic Exploration with Control of Directional Sensitivity. A system of seismograph shooting in which the line of detectors is perpendicular to the strike and the difference between detector signals is recorded so as to give sensitivity to reflections from steeply dipping beds.

368—SEISMOGRAPH TIMING

U. S. No. 2,428,369. E. W. Kammer. Iss. 10/7/47. App. 12/14/45.

Optical Time-Base Generator. A system for obtaining on a photographic record tape a zero line having bright spots at the time interval marks.

U. S. No. 2,433,160. G. W. Rusler. Iss. 12/23/47. App. 9/6/45. Assign. Minneapolis-Honeywell Regulator Co.

Tuning Fork Construction. A temperature-compensated tuning fork which has an auxiliary mass mounted on each tine by a bimetallic strip.

372—SEISMOGRAPH VOLUME CONTROL

U. S. No. 2,430,246. R. G. Piety. Iss. 11/4/47. App. 7/25/44. Assign. Phillips Petroleum Co.

Automatic Volume Control for Seismograph Amplifiers. An avc system for multichannel seismograph recording in which each amplifier's signal is separately rectified and the combined rectified currents used to simultaneously control all amplifiers.

U. S. No. 2,430,983. H. Hoover, Jr. Iss. 11/18/47. App. 7/24/39 and 11/24/41. Assign. United Geophysical Co., Inc.

Seismic Amplifying System. An expander system for seismograph amplifiers in which the time sensitivity function is changed by means of thyratron-controlled relays which change the resistance across a condenser.

428—STRAIN GAUGE

U. S. No. 2,428,433. N. H. Roy. Iss. 10/7/47. App. 11/17/43. Assign. Waugh Equipment Co.

Strain Measuring Apparatus. An electric strain gauge in which the filament is cemented to the specimen, the cement allowed to dry or cure, and the unit then covered with an impervious sealing material to prevent further drying and embrittlement.

U. S. No. 2,429,087. F. Aughtie, F. R. Thurston and E. P. Coleman. Iss. 10/14/47. App. 10/8/42 and 10/8/43.

Electrical Resistance Strain Gauge. A filament-type strain gauge in which the filament is helically wound on a card and covered and bonded with a thin insulating sheet.

U. S. No. 2,429,248. N. T. Volsk. Iss. 10/21/47. App. 5/17/43.

Mechanical Pressure Gauge. A cylinder pressure gauge for an internal combustion engine in which the pressure is applied to a small piston which stresses two concentric tubes in tension and compression, the motion of the piston being indicated by a connection to a mirror which reflects a light beam.

U. S. No. 2,431,260. B. F. Langer. Iss. 11/18/47. App. 8/25/44. Assign. Westinghouse Electric Corp.

Torque Measuring Device. A torque measuring apparatus having a copper sleeve on the shaft, then an insulating layer of powdered iron and a short-circuited filament-type strain gauge wound on it and an outer stationary annular coil connected in an a-c bridge circuit.

432—SUBMARINE LOCATOR

U. S. No. 2,432,625. G. J. Klein. Iss. 12/16/47. App. 7/10/43. Assign. Western Electric Co., Inc.

Apparatus for and Method of Locating Submarines. A system for locating enemy submarines from a convoy by observing on two ships the underwater sounds from the submarine, transmitting the signals by radio to another ship where they are recorded on separate magnetic tapes and reproduced with an adjustable time displacement on quadrature plates of a c.-r. tube, sounds from the same source being identified by producing a straight line c.-r. trace and its location being determined by triangulation.

U. S. No. 2,433,385. O. R. Miller. Iss. 12/30/47. App. 11/5/42. Assign. Bell Telephone Laboratories Inc.

Submarine Locating System. An echo distance-measuring system in which a standard frequency wave train is transmitted and the pulses counted, the length of the train being adjusted so that the transmitted train is stopped just before the echo is received.

436—SUBMARINE SIGNALING

U. S. No. 2,428,821. E. E. Turner, Jr. Iss. 10/14/47. App. 7/19/43. Assign. Submarine Signal Co.

Method and Apparatus for Sound Ranging. A submarine sound ranging system in which two supersonic frequencies are directionally transmitted and the receiver uses a square law detector to indicate the beat signal.

U. S. No. 2,431,018. W. J. A. Bailey and H. A. Panissidi. Iss. 11/18/47. App. 3/26/43. Assign. International Business Machines Corp.

Sound Detection System and Apparatus. A submarine sound system for detecting and locating ships using off-shore stations which pick up the sound and relay it by radio to a relay station from which it is transmitted to a shore station for analysis.

U. S. No. 2,431,026. F. P. Bundy. Iss. 11/18/47. App. 1/21/44. Assign. U.S.A.

Magnetostrictive Oscillator. A cylindrical magnetostrictive hydrophone having a nickel tube with a polarizing magnet along the diameter and coils on a form inside the tube.

U. S. No. 2,432,083. R. Black, Jr., F. F. Romanow and O. A. Shann. Iss. 12/9/47. App. 12/8/42. Assign. Bell Telephone Laboratories, Inc.

Hydrophone. A hydrophone having an inertia-type transducer mounted on the flat side of a D-shaped frame which slides into a thin-walled container coated on the outside with a thin layer of rubber.

U. S. No. 2,433,332. H. Benioff. Iss. 12/30/47. App. 10/22/41 Assign. Submarine Signal Co.

System for Locating Obstacles. A multi-channel compressional-wave harbor-protection system in which impulses are sent out and the reflection picked up by receivers directed to cover various parts of the area, each receiver being connected to an indicator moved across the recording chart proportional to the speed of sound in water and an indication made when the reflection is received.

U. S. No. 2,433,337. R. M. Bozorth. Iss. 12/30/47. App. 1/19/43. Assign. Bell Telephone Laboratories, Inc.

Magnetostrictive Signal Translating Device. A magnetostrictive hydrophone having a core in the form of a closed rectangular loop with one pair of parallel legs of material having a positive magnetostrictive coefficient and the other pair with a negative magnetostrictive coefficient.

U. S. No. 2,333,361. B. M. Harrison. Iss. 12/30/47. App. 1/20/40. Assign. Submarine Signal Co.

Method and Apparatus for Echo Ranging. A supersonic echo distance-measuring system which transmits a signal whose frequency is continuously varied at a high audio frequency and the echo used to produce an audio signal which operates a timed indicator.

460—THERMOMETER

U. S. No. 2,431,625. W. A. Tolson. Iss. 11/25/47. App. 2/26/43. Assign. Radio Corp. of America.

Heat Detecting System. A self-orienting directional heat-sensitive detector mounted on the wing tip of an aircraft and connected by Selsyn to automatically set correct gun elevation.

468—TIME INTERVAL METER

U. S. No. 2,433,254. W. R. Aiken. Iss. 12/23/47. App. 1/7/46.

Electrical Timing System. A resistance-capacity circuit for operation timing in which auxiliary relays are operated through neon tubes.

U. S. No. 2,433,667. G. L. Hollingsworth. Iss. 12/30/47. App. 12/29/43. Assign. General Electric Co.

Time-Measuring Apparatus. A time interval meter for a radio pulse echo system in which a square wave is initiated on transmission and terminated on receipt of the echo, the time measurement being obtained by integrating the square-wave impulse and converting to a peaked wave whose peak amplitude is indicated.

484—TRANSDUCER

U. S. No. 2,430,028. W. G. Pfann, J. H. Scaff and A. H. White. Iss. 11/4/47. App. 3/16/43. Assign. Bell Telephone Laboratories, Inc.

Translating Device and Method of Making It. A method of shaping the contact end of a fine wire for use with a rectifying crystal as a microwave detector by grinding a conical point on the wire, electrolytically polishing the cone and subjecting the point to a force large enough to produce upsetting.

U. S. No. 2,430,476. E. F. McClain, Jr. Iss. 11/11/47. App. 8/25/43.

Phonograph Reproducer. A moving coil electromagnetic phonograph pickup in which the coil is mounted on the free end of a wire which is given torsional vibrations by the stylus.

U. S. No. 2,431,026. F. P. Bundy. Iss. 11/18/47. App. 1/21/44. Assign. U.S.A.

Magnetostrictive Oscillator. A cylindrical magnetostrictive hydrophone having a nickle tube with a polarizing magnet along the diameter and coils on a form inside the tube.

U. S. No. 2,431,367. W. H. Bussey. Iss. 11/25/47. App. 1/22/45. Assign. O. W. Storey & Associates.

Capillary Electrometer Apparatus. A transducer having a capillary electrometer tube in pressure communication with a liquid-filled Bourdon tube.

U. S. No. 2,431,841. A. W. Storm. Iss. 12/2/47. App. 10/12/45. Assign. Hartford National Bank & Trust Co.

Apparatus for Measuring Relative Displacement or the Thicknesses of Materials. A variable-capacity-type thickness or displacement gauge in which a.c. is supplied to the gauge capacity in series with a second condenser, the latter being connected to the indicator.

U. S. No. 2,432,218. A. Vang. Iss. 12/9/47. App. 7/15/44.

Apparatus and Method for Generating Sound. A sound generator having a mechanically resonant system which is driven by a unidirectional pulsating force obtained by supplying pulsating current to an electrodynamic driving unit.

U. S. No. 2,432,444. B. Roberts. Iss. 12/9/47. App. 6/29/44. Assign. Philco Corp.

Phonograph Pickup Device. A variable-capacity-type phonograph pickup in which the condenser is formed of a rigid plate and a thin strip which is vibrated by the stylus.

U. S. No. 2,433,337. R. M. Bozorth. Iss. 12/30/47. App. 1/19/43. Assign. Bell Telephone Laboratories, Inc.

Magnetostrictive Signal Translating Device. A magnetostrictive hydrophone having a core in the form of a closed rectangular loop with one pair of parallel legs of material having a positive magnetostrictive coefficient and the other pair with a negative magnetostrictive coefficient.

490—VEHICLE

U. S. No. 2,432,107. A. R. Williams. Iss. 12/9/47. App. 12/30/42.

Amphibian Vehicle. An armored amphibian vehicle having bulbous wheels with sufficient buoyancy to float the vehicle and with a separate air-cooled engine inside each wheel coupled to the wheel through a fluid drive.

492—VIBROMETER

U. S. No. 2,428,671. E. L. Kent and R. C. Treseder. Iss. 10/7/47. App. 5/9/44. Assign. Kent to C. G. Conn, Ltd.

Vibration Apparatus. An adjustable reed having longitudinally movable supports which roll along the reed and change its length so that it may be tuned to resonance.

U. S. No. 2,429,094. E. L. Kent and R. C. Treseder. Iss. 10/14/47. App. 5/9/44. Assign. Kent to C. G. Conn, Ltd.

Apparatus for Measuring Mechanical Vibrations. A vibrating reed of adjustable length and having a magnetic bridge type pickup.

496—VISCOSIMETER

U. S. No. 2,431,378. L. C. Eitzen and W. C. Schwaderer. Iss. 11/25/47. App. 4/15/44. Assign. L. C. Eitzen.

Viscosimeter. A viscosimeter having a cup-shaped falling body provided with a circumferential lip around the upper rim and one or more openings in the bottom.

REVIEWS

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Theory of Electrical Well Logging by L. M. Alpin. Moscow, 1938. Pp. 88.

Alpin's book deals with the calculation of departure-resistivity curves for the case of formations infinitely thick and invaded by mud.

The method of calculation is explained in detail and a number of typical departure charts are given for two- and three-electrode arrangements. Inasmuch as these charts are only examples, they do not cover a very wide range of conditions. However, with the help of the numerous tables available in the book the reader can establish with little effort almost any desired departure curve.

An interesting chapter deals with the equivalence principle. Alpin has found that, under certain conditions, departure curves established for formations having given physical characteristics are practically identical to those of formations having different characteristics. The equivalence condition is expressed as follows:

$$(R_i/R_m - 1)\ ln\ D/d = \text{constant},$$

where: R_i is the resistivity of the mud-invaded zone,
R_m the mud resistivity,
D the diameter of the mud invaded zone,
d the hole diameter.

The foregoing equation may be used only when the ratio D/d falls between the limits 1.2 and 4, and also only when the resistivity R of the non-invaded zone is less than R_m.

Notwithstanding these limitations, the equivalence principle is useful to establish quickly departure curves corresponding to certain resistivity distributions.

Although the same remark probably applies to other cases also (provided a different equivalent equation is used), the principle is not generalized by Alpin, except for the case of formations having a very high formation factor F and exhibiting an extremely small degree of invasion. In this case the equivalence condition is:

$$(D/d - 1)\frac{R_i}{R_m} = \text{constant}.$$

Alpin's book is extremely valuable to the geophysicist. On the other hand, it is so purely theoretical that probably but few geologists will be interested in this treatment.

HUBERT GUYOD

Electrical Well Logging. Interpretation of Electric Logs by V. N. Dakhnov. Moscow, 1941. Pp. 496.

While Alpin's book deals only with the theory of resistivity logging, Dakhnov's treatment discusses all the practical aspects of electrical logging for the benefit of the geologist, petroleum engineer, geophysicist and well-logging operator.

The book is divided into twelve chapters, namely:

1. Effect on resistivity graphs of the nature and characteristics of the beds traversed by a bore hole.
2. Lateral investigation. Method of determining true resistivity of formations.
3. Natural electric potentials in bore holes.
4. Induced polarization.

5. Effect on temperature graphs of the nature and characteristics of the formations surrounding bore holes.
6. Data for determining the relation between mechanical logs and the physical and geological characteristics of formations traversed by bore holes.
7. Simultaneous interpretation of various logs.
8. Normal and composite logs.
9. Use of electric logs for correlations.
10. Use of electric logs for geological mapping.
11. Use of electric logs for determining productivity of reservoirs.
12. Regional data on electric logs.

Inasmuch as there is considerable overlapping between the chapters, a general outline of the whole work is offered here, rather than a separate summary of each chapter.

In the first sections of his book, Dakhnov discusses the effect of porosity, interstitial water, salinity, and saturation on the resistivity of reservoirs. The Russian field and laboratory data agree fairly well with similar data previously available in this country. The methods of investigation used seem to be the same as those applied in the United States.

The following sections discuss at length the relation between apparent resistivity and true resistivity. The method for calculating the apparent resistivity as a function of the various factors involved is given for two- and three-electrode arrangements. Numerous examples are given to illustrate the respective influence of the factors involved (resistivity contrast, bed thickness, and mud column). Although these discussions do not bring forth any important fact which we did not already know, they cover the subject much more thoroughly than any other publication on the subject. In particular, the important and difficult case of high-resistivity formations is discussed at length.

Departure-resistivity curves for invaded and non-invaded formations illustrate the preceding discussions.

Some scattered information is available also on the combined influence of several of the factors involved, in particular when both the bed thickness and the mud column are considered. A few experimental resistivity logs (scale-model data) illustrate the effect of thin conductive streaks situated in resistant formations. The examples given are unfortunately too few to permit the reader to account for non-uniformity in the interpretation of electric logs.

Other new data include a short discussion of the influence of formation dip and of the electrode diameter.

The application of the foregoing data to the determination of true resistivity is illustrated by experimental curves. The interpretation is done primarily by curve matching; however, the number of charts and other data are not sufficient always to permit a satisfactory determination of the resistivity.

The chapter dealing with bore-hole potentials discusses at length the possible effects of concentration potentials and streaming potentials. Although some interesting remarks are to be found in Dakhnov's book, it does not seem to the reviewer that a satisfactory theory is offered to account for these potentials. This should not be construed as a criticism since we have not made much progress ourselves on the subject, notwithstanding some occasional interesting communications by American experimenters.

The potential chapter is illustrated by a number of graphs obtained in coal beds. Bore-hole potentials in coal are usually positive with respect to the surrounding rocks. Several hundred millivolts are frequently observed opposite coal seams.

The induced-polarization chapter comprises only a few pages. It is doubtful that useful data on this subject have been obtained in the U.S.S.R. This little-known phenomenon, discovered by Conrad Schlumberger, is manifested by residual potentials which exist for a short duration after a direct current is passed through a formation.

The section on temperature logging, comprising about eighty pages, discusses the various applications of the method. Dakhnov's book does not mention any development which is not already known in the United States.

The chapter on mechanical logging (ten pages) gives some data on rock hardness and drilling rates. It is illustrated by several mechanical logs. This discussion is primarily concerned with the fundamentals of the method.

The seventh chapter of the book is concerned with the discussion of well logs comprising several graphs, namely: potential, resistivity, and sometimes temperature and/or drilling rate. Logs showing the general parallelism between potential and mechanical logs in soft formations, and between resistivity and mechanical logs in hard formations are given as examples. A special section is devoted to the discovery of coal from the simultaneous use of various graphs. While the depth and exact thickness of coal seams are usually difficult to determine from drilling and coring data alone (because most coal beds are very brittle), the problem can generally be solved by supplementing the mechanical log with an electric log. Most coal seams are characterized by a high resistivity and a high drilling rate, and sometimes by a positive potential. These properties are typical of coal in most carboniferous provinces.

Most other applications of electric logs discussed in Dakhnov's book are well known in this country, except the study of the productivity of petroleum reservoirs. Inasmuch as the petroleum saturation markedly affects the resistivity of a formation, it is sometimes possible to determine from adequate electric logs the saturation and its decline in terms of time.

Dakhnov's book is illustrated by numerous logs and charts. In addition, tables give some electrical characteristics of the formations commonly found in the Russian oil fields.

Every type of information pertaining to electrical logging can be found in this treatment, with the exception of descriptions of logging equipment.

When reading Dakhnov's book we should not forget that it was published in 1941 and that it discusses data which are now at least eight years old. At that time no comprehensive contribution to electrical logging was available in the American literature. Dakhnov's work is evidence of the great amount of research done in the U.S.S.R. shortly after the introduction of the method in that country.

Notwithstanding the wealth of information available in this book the reader will probably be disappointed when he fails to find in it a satisfactory method of log interpretation. As a matter of fact, although the author presents a comprehensive discussion of electrical logging, he has not been entirely successful in showing how the data can be used to secure the desired formation characteristics. It is true that there is considerable information explaining how the true resistivity of a reservoir can be determined from an electric log, but the practical man is interested primarily in petroleum saturation, porosity and permeability, and not in resistivity and potential, and Dakhnov does not explain satisfactorily how the reservoir characteristics can be estimated from a log. This, however, should not be considered as a criticism: we must remember that it is not possible to establish a sound method of interpretation before the fundamentals of electrical logging are well understood. Dakhnov has done this analytical work excellently, but at that time he could not have had the opportunity to translate his findings into a comprehensive method of interpretation.

HUBERT GUYOD

"An Investigation into the Value of the Seismic Methods in Delineating Structure in Southwestern Ontario" by John H. Hodgson. *56th Annual Report of the Ontario Department of Mines*, Vol. 56, Part 4 (1947).

Almost every field party doing seismic reflection shooting has encountered areas in which no reflections at all can be picked up even though every known remedial device is tried. But seldom in the annals of seismic prospecting do we have a record of such unmitigated difficulty as that recorded in the current paper by Dr. Hodgson. He was geophysicist on a field survey designed to test the various geophysical methods in the search for new natural gas fields in southwestern Ontario during 1945 and 1946.

The seismic method was investigated after gravitational and magnetic techniques had been found highly unpromising since the fields originating from the basement seemed to overshadow any varia-

tions in the overlying sediments. A preliminary examination of the stratigraphic section indicated that there were two surfaces, the base of the Guelph and the top of the Trenton, that might be expected to give reflections because of the sharp lithology contrast at each horizon. A 1,400-foot well was shot to secure a vertical velocity log which showed an average velocity to the bottom of more than 14,000 ft/sec.

The actual field tests were conducted in eight different areas, well distributed throughout the gas district of southwest Ontario. Only in one area, called the Malden prospect, were any reflections obtained. These were not good, but they could be correlated over a mile of profile and the conclusion was reached that this area would probably be workable with modern instruments. In the seven other areas every known device, such as use of multiple and mixed detectors, varying of shot-hole depth and changing of spread layout, was attempted but all to no avail. Expert advice was sought from consultants in the States who concluded that failure was attributable to natural geological conditions rather than to inadequate technique.

Causes of failure might be summarized as follows:

1. Speeds were so high and depths to the basement so low that reflections from the lowest possible sedimentary horizons would return in less than half a second. The compression of all possible reflections from different horizons into such a narrow space on the record would make correlation difficult, as would interference from later cycles of first-arrival impulses.

2. In regions of thick drift, any reflections would be obscured by several curious refraction phases observed in the area and identified as refractions from step-out times. These are believed to come from layers within the till overburden even though times are too great for them to be simple refractions of the conventional type. The mechanism appears to be little understood and the explanation given is highly questionable.

3. The high velocities magnify the effect of error in surface corrections, resulting in an uncertainty in depth determination that is excessive in view of the low structural relief of the gas fields in the region.

4. The drift greatly attenuates seismic waves.

After the possibilities of using the reflection method are discounted for these reasons, the feasibility of using seismic refraction is discussed briefly. Although the technique has not been tested in the area, it is not considered promising since structures are smaller than can usually be resolved by this method.

In spite of the fact that the reported results are almost entirely negative, the paper is useful in that it shows the limitations of geophysical methods and demonstrates quite clearly how a combination of perverse geologic factors can render unavailing all the resources of the seismographer's art.

MILTON B. DOBRIN

"Oil Fields of Greater Oficiana Area Central Anzoategui, Venezuela," by H. D. Hedberg, L. C. Sass, and H. J. Funkhouser. *Bull. A.A.P.G.*, *31* (1947). Pp. 2089–2169.

This is an excellent geological report on one of South America's most important oil producing areas. It should be a highly interesting region to exploration geophysicists, since geophysical methods were responsible for its initial discovery and during the course of its development every one of the standard prospecting techniques was employed at one time or another with varying degrees of success. The complete story of how geophysical methods have been utilized at Oficina and in other areas of eastern Venezuela would make a most valuable and instructive case history, which one hopes will be forthcoming. But until the details are released and published, the brief outline presented in this paper must suffice.

The Oficina No. 1 wildcat, located by a combination of torsion-balance and refraction-seismograph data, was the first well to be drilled in the interior plains of eastern Venezuela; its successful completion in 1936 led to an exploration and drilling campaign that has already resulted in the production of 175,000,000 barrels of oil in this province. The Greater Oficina producing area is a strip 50 miles long that contains a number of separate pools. Accumulation is governed chiefly by normal

faults, although pinch-out on one or two sides is often instrumental. Folding is very sparse and when it occurs it is superimposed on the gentle northward regional dip, which is always less than 5°. Oil reservoirs are all sandstone bodies in the Oligocene-Miocene Oficina formation. The sedimentary section, consisting of detrital Cretaceous as well as marine and brackish-water Cenozoic deposits, ranges from about 6,000 to 7,000 feet in thickness and is underlain by an igneous-metamorphic rock of complex composition. The faults responsible for the oil traps generally continue into the basement.

With this kind of geology it is not surprising that all of the geophysical exploration methods were not equally fruitful. At first, the area was surveyed with the torsion balance and by refraction-seismograph shooting on a reconnaissance basis. All wildcat locations prior to 1937 were determined by the indications of these two methods. From 1936 to 1938 refraction work was continued on a basis that made possible closer mapping of detailed structure. Evaluating this, the authors remark that the results as interpreted at the time show little accordance with structure as now known. Be that as it may, the method seems to have had a good record as far as location of oil in the area is concerned.

In 1937, the magnetometer brought out pronounced trends in the basement which again could not be correlated very successfully with sedimentary structures controlling oil accumulation. A detailed gravimeter grid in 1940 was of little practical use, and subsequent soil analysis and surface electrical prospecting gave results which cannot be evaluated as yet.

Since 1939, when it was initiated, reflection-seismograph work has turned out to be the most valuable geophysical tool of all. Continuous profiling has given reliable enough phantom horizons to permit location of the faults which are most significant in governing the accumulation of oil here. Closely allied with the reflection shooting has been structure drilling to depths of 3,000 feet, with portable rigs, with reliance on electric logging rather than cores for correlation. The combination of the two has been by far the most effective means of exploration, and is now firmly established as an essential prerequisite to all exploration drilling.

The entire area has been especially favorable for correlation by the electric log, and structure, and isopach maps have been based on this rather than on paleontology or lithology. Most of the productive sands appear to correlate fairly well with the resistivity curves of the log.

The paper is unusually well organized and the material is presented in a clear and interesting manner. If the geophysical history outlined in it were expanded into a companion paper, the two together would represent a significant contribution to the literature of petroleum geophysics.

MILTON B. DOBRIN

"Biochemical Prospecting for Copper and Zinc," by H. V. Warren and C. H. Howatson. *Bulletin Geological Society of America, 58* (1947). Pp. 803–820.

This paper appears to give quite definite indications that the amounts of copper and zinc in certain plants are definitely related to the concentration of these metals in soils where the plants have grown, and suggests that similar analyses might be a useful method of prospecting for copper and zinc ore bodies.

These tests were made in copper and zinc mining areas in British Columbia. The general scheme was to take samples of plants from areas which were known to contain copper or zinc deposits and controls from areas not containing ore. Since the entire territory is glaciated it was necessary to take the controls from areas where exploration had been carried out with negative results to be sure that these control samples were not over copper or zinc deposits covered by glacial drift.

The general procedure was to take samples from cones, bark, wood, leaves, etc., of the various plants and to test the ash from these parts by the analytical methods used in normal assaying. The methods were capable of showing traces of copper and zinc to about 1 part per million of the original material.

The tests showed definitely higher copper and zinc content in certain parts of the plants growing on "positive" areas, over deposits containing one or the other of these metals than in the controls which grew on "negative" areas with no underlying deposits. Certain parts of the plants are much more sensitive than others. For instance, the cones of hemlock, lodge-pole pine and Douglas fir and

the leaves of green alder and Devil's club from "positive" areas showed copper or zinc content from 20 to 80 times greater than the controls from "negative" areas.

A very extensive bibliography is almost entirely from botanical and agricultural publications, with additional titles (supplied by H. E. Hawkes of the U. S. Geological Survey) of German, Scandinavian and Russian references.

The work seems to indicate that the application of tests of this kind to the proper parts of selected plants could lead to a useful method of prospecting. To a certain extent the normal mineral copper and zinc contents have been established so that the magnitude of metal content which would probably be indicative of a local mineral deposit is determined. If more rapid methods of analysis (possibly quantitative spectroscopy) could be applied so that large numbers of samples could be analyzed quickly, an economically useful process might be developed. Apparently much remains to be learned as to the best plants and part of the plants to use and the season of growth at which they are most sensitive.

L. L. NETTLETON

"The Zinc Content of Plants of the Friedensville Zinc Slime Ponds in Relation to Biogeochemical Prospecting," by W. O. Robinson, H. W. Lakin, and Laura E. Reichen. *Economic Geology*, XLII, (1947). Pp. 572–582.

Ever since the Middle Ages instances have been reported where the presence of certain "indicator plants" has led to the discovery of mineral ores. Scrub black-jack oak, for example, has been recognized as characteristic of serpentine terrain and used as a guide in prospecting for chromium, which is often associated with this intrusive. Except for a few scattered Scandinavian and German publications, however, there have been no reports, until the simultaneous appearance of this paper and one by Warren and Howatson[1] from British Columbia, of any quantitative studies on the relation between the metallic content of plants and the concentration of metals in the underlying ground. These two papers are the first to present data with which one can evaluate the feasibility of prospecting for metals by chemical analysis upon plants.

The survey described by Robinson and his co-workers was a joint study by the U. S. Department of Agriculture and the U. S. Geological Survey into the characteristics of plants grown on soil abundantly rich in zinc. The vegetation on slime or tailing ponds in which the waste products from adjacent zinc mines have accumulated for many years was believed to be ideal for such a study, and samples were collected from two such ponds in the Friedensville, Pa., area. The soil in the ponds was analyzed and found to contain 12.5 percent zinc. A large suite of sp- -s was taken from each pond on two collecting trips a month apart. Zinc concentrations of each plant were analyzed by techniques previously developed for soil analysis.

The specific objectives of the investigation were to measure the absorption of zinc by different plants, to look for unusual plants whose presence could be shown as indicative of high zinc concentration in the soil, and to observe any abnormalities in the plants which could possibly be associated with the zinc and hence could be found useful in prospecting.

The plants were all found to contain measurable quantities of zinc but there was enormous variation in the concentration of the element as found in various species. This ranged from 7,000 parts per million in a sample of horsetail to 39 p.p.m. for the fruit of the Solomon's seal. As controls, samples were taken of the same plants from nearby areas away from the slime ponds and also from points more than 100 miles distant. The zinc concentrations of the plants grown on the ponds were roughly ten times as high as those of the controls.

Results were not felt to be conclusive, but the investigators pointed out that ragweed, horsetail, and poplar leaves offered promise as indicators of zinc in the ground. Of these, the poplar-tree leaves were believed to offer the best possibilities for biogeochemical prospecting, since the poplar roots penetrate farthest and the tree is most widely distributed geographically. Only one plant gave any

[1] H. V. Warren and C. H. Howatson, "Biogeochemical Prospecting for Copper and Zinc," *Bull. Geol. Soc. America*, *58* (1947), 803–820.

indication of being a possible "indicator" of zinc, and even there the likelihood was considered remote. This was the *Tomantheria auriculata*, which is found only in the zinc areas of Pennsylvania and Missouri. There was no conclusive evidence that any abnormalities in the plants could be directly attributed to the zinc.

Before any conclusions can be drawn as to the value of this technique in prospecting for zinc, it would appear that data should be obtained on zinc concentrations in plants growing on less artificial zinc-bearing ground than the tailing ponds. The work reported by Warren and Howatson appears to have been in this direction and their results also indicate favorable possibilities for prospecting applications.

The current paper has an excessively lengthy historical introduction (nearly three pages out of eleven) and it suffers somewhat from loose organization. In spite of this, it is highly readable to the botanical layman and it may some day be looked back upon as a pioneering paper on a standard prospecting technique.

MILTON B. DOBRIN

La Prospection Electrique du Sous-Sol (Electrical Prospecting) by E. Poldini. Lausanne, 1947. Pp. 120.

The phrase, "a brief elementary textbook on the subject of electrical prospecting," would accurately describe the book were it not for the somewhat more advanced treatment accorded to a few important phases of this broad subject. Only a dozen references are cited, and the absence of an extensive bibliography is felt throughout the entire book. This is one of the reasons why the volume cannot be considered as a standard comprehensive reference work in the field of electrical prospecting.

The section dealing with anisotropy which is important to the understanding of certain phenomena occurring in electrical prospecting is presented in some detail. A mathematical treatment to support the explanations is also included, and the development of the term "apparent anisotropy" is quite complete. Several quantitative examples are also included in the discussion of this subject. The concept of electromotive forces resulting from the movement of subsurface waters is also developed in some detail.

His treatment of the subject of telluric currents which constitutes an important phase of electrical prospecting is not very complete. However, an example of changes in the telluric potential gradient over a salt mass overlain by sedimentary beds and alluvium in the Alsatian plain is very interesting. The lack of important references is again very conspicuous in the section in which telluric currents are discussed. For example, no mention is made of the comprehensive treatment of this subject in Chapman and Bartels' *Geomagnetism*, Oxford University Press, London, 1941.

It is difficult for the reviewer to understand why such subjects as thermal and several other well-logging methods together with gun perforating are discussed, although very briefly, in a book which apparently is directed exclusively to the subject of electrical prospecting.

R. A. GEYER

"Anwendung der Fourier-Sätze in der Theorie der Seismographen und Schwingungsmesser" (Application of Fourier Analysis in the Theory of Seismography and Oscillatory Measurements) by F. Gassman. *Elemente der Mathematik, Mitteilungen aus dem Institut für Geophysik*, Bd. 11/3, (1947). Pp. 58–63.

A brief, well-written expository article is always a refreshing morsel, particularly in matters mathematical. Here we have a concise résumé of those elementary theorems in Fourier Series and Integrals which are basic in first discussions of oscillatory phenomena. Nothing new or advanced, nothing proved or rigorously stated, is contained in the presentation, but it does provide an excellent and ready reference for the pertinent elementary relations, expressed in the notation of the complex variable. It seems that the treatment is designed to explain to the mathematician the physical significance and application of Fourier Theory. The discussion, in fact, ends with the relationships between the input and output of an electro-mechanical system, although the requirements on such a system in order that it be amenable to Fourier Analysis are not clearly stressed.

M. M. SLOTNICK

"Mesures de Pesanteur Executees dan Le Sud-Est de la France en 1941. Description Gravimetrique de la Region Nord des Alpes Francaises" (Gravity Observations Made in the Southeast of France in 1941. Gravimetric Description of the Region North of the French Alps) by Pierre Lejay. *Comite national francaise de geodesie et geophysique.* Paris, 1942. Pp. 89–95 and 97–102 and map facing 102.

A Bouguer-anomaly map for the southeast of France based on 154 stations, and assuming a density of 2.7, is included together with the necessary data in tabular form. Lejay believes on the basis of these data that the zone of isostatic compensation for the Alps coincides with the axis of the crystalline-massiff area and is situated at a relatively shallow depth. For example, Bouguer values of −186 milligals are found over the Pelvoux, Vanoise, and Mont Blanc massiffs. In contrast to these large negative values, Bouguer anomalies of −8 and −10 milligals are found in the vicinity of Lyon. This contention is in keeping with Heiskanen and Salonen's statement appearing on page 18 of the "rapport sur l'isostasie congrés de Lisbonne 1933" to the effect that the depth of compensation of the Swiss Alps is of the order of 35 kilometers. Lejay attributes the higher values of the Rhone Valley region to the presence of denser igneous rocks at and near the surface in the area.

R. A. GEYER

"Mesures de Pesanteur Executees dans le Sud de la France en 1940. Etude Theorique de l'Attraction des Couches Minces. Application a l'Interpretation des Anomalies Regionales" (Gravity Observations Made in the South of France in 1940. Theoretical Studies of the Attraction of Thin Beds. Application to the Interpretation of Regional Anomalies) by Pierre Lejay. *Comite national francaise de geodesie et geophysique.* Paris, 1942. Pp. 52–98.

A Bouguer-anomaly map for the south of France based on 99 stations is included together with the necessary data in tabular form. The negative Bouguer values of the order of 100 milligals and more found along the French-Spanish frontier undoubtedly reflect the presence of the Pyrenee Mountains. These values decrease steadily going towards the north to −29 and −3 milligals at Toulouse and Alps respectively. However, in several zones in this area it is believed that the effect of masses situated at shallower depths have a tendency to mask the regional picture. The major portion of this article is directed toward the derivation of formulas used in applying the necessary topographic corrections for the area surveyed, and the derivation of formulas and graphs to be used for calculating the gravitational effect of beds dipping at various angles. The article concludes with a discussion of the interpretation of certain regional anomalies based on the formulas and methods developed in the earlier section.

Lejay maintains that the results to be obtained by these methods should be considered as indicative of the order of magnitude of the depth and dip of the beds rather than a precise delimitation of these features. However, when certain geologic information is available in conjunction with the gravity data, he believes that these methods can be made more definitive. These generalizations are similar to those made by D. C. Skeels in a recent article appearing in *Geophysics* entitled "Ambiguity in Gravity Interpretation," January, 1947.

R. A. GEYER

Research, A Journal of Science and Its Applications. London: Butterworths Scientific Publications Ltd., October, 1947.

A new journal entitled *Research, A Journal of Science and Its Applications*, was published for the first time in London in October, 1947. Its objectives may be summarized by the following quotation:

> "In Scope, *Research* will be found to differ materially from any other Journal. It is not a journal of pure research. It will not specialize, for it favours no particular field of endeavour. On the other hand it is not a mere organ of applied science: still less will it be found to compete with the technical and trade journals."

It is conceivable that articles of interest to the readers of *Geophysics* would appear in a journal of this type from time to time. For example, in the November, 1947, issue a paper by James Taylor entitled "Advances in British Commercial High Explosives" definitely falls into this category. It contains a section dealing specifically with explosives used in oil prospecting. The original reference to the Monroe Effect together with those pertaining to its commercial application in the field of oil exploration and exploitation is included; as well as an extensive bibliography on other phases of explosives.

R. A. GEYER

Nucleonics, (The McGraw-Hill Magazine of Nuclear Technology). October, 1947.

The first issue of a new journal devoted exclusively to nuclear physics entitled *Nucleonics* published in New York by the McGraw-Hill Publishing Company appeared in September, 1947. The objectives of this periodical may be found from the following quotation appearing in the editorial:

> "A step toward the solution of some of the problems posed by expanding activity in the nuclear energy field has been made by the founding of *Nucleonics*. This journal will make available a disinterested medium for reporting important advances in all phases of applied nuclear physics."

This journal should prove to be of interest to many in the field of geophysical prospecting because of the varied uses of radioactivity in this field. In addition to such articles as 'Radioactive Units and Standards" by R. B. Evans in the October issue, a list of 267 de-classified Manhattan District documents appears in the September issue and a supplement in the October issue. The editors plan to continue to make additional listings available when they are made public. This journal also carries an abstract section for articles in the field of nucleonics appearing in other periodicals.

R. A. GEYER

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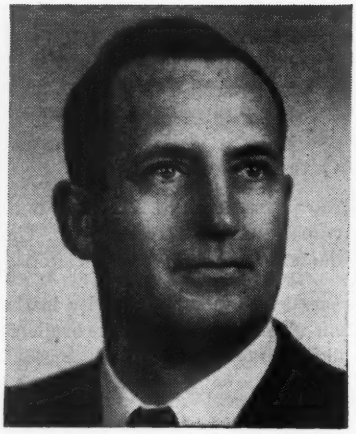
CONTRIBUTORS



JOHN W. DALY

JOHN W. DALY received the B.S. degree in Science and the M.S. degree in Geology and Paleontology from the California Institute of Technology. Following the completion of his work there in 1930, he joined International Geophysics, Inc. as geologist. In 1933 he was employed by Shell Oil Company, Inc. and was successively draftsman, assistant seismograph observer, assistant seismologist, seismologist, geologist. In 1942 he resigned from Shell and shortly thereafter was employed by the Honolulu Oil Corporation. A few months after joining Honolulu he was transferred from California to Texas where he has been in charge of their seismograph work.

FRANCIS A. VAN MELLE was born in Amsterdam, the Netherlands, in 1903 and received the degree of Ph.D. from the University of Groningen in 1928 on a thesis, "X-ray Investigations on the Symmetry of the Carbon Atom." Immediately afterward he entered the service of the B.P.M., technical subsidiary of the Royal Dutch Oil Co., as gravity party chief and seismologist in the Dutch East Indies and Mexico. He left the B.P.M. in 1937 and imigrated to this country. The next year he entered the service of the Shell Oil Co., Inc. as seismologist in charge of an experimental crew. Since 1943 he has been research seismologist in Shell's Exploration and Production Research Laboratory.

F. A. VAN MELLE

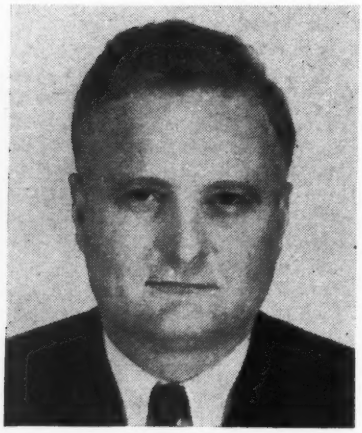
GARVIN L. TAYLOR received the degree of A.B. in Geology from the University of Wichita in 1929. He was employed for two years by Lee and Garlough, consulting geologists, in Kansas doing surface and subsurface geology. He received the degree of Ph.D. in geology from the University of Iowa in 1934 and has been employed by the Stanolind Oil and Gas Company since that time. From 1934 to 1937 he did geological work in Kansas, and from 1937 to 1942, he did geological work connected with seismic operations in Kansas, Oklahoma, and Texas. Since 1942, he has been doing geological interpretation of geophysical data.

GARVIN L. TAYLOR

DUANE H. RENO

DUANE H. RENO studied geology at the University of Colorado and received a B.A. degree in 1937, and an M.A. in 1939. He worked thereafter for the U. S. Engineers in Kansas, Oklahoma, Missouri, and Tennessee in core-drilling exploration of dam-site foundations. In 1941 he was employed by the Stanolind Oil and Gas Company, and has been located at their Exploration Research Laboratory since 1942.

Mr. Reno is a member of the American Association of Petroleum Geologists.



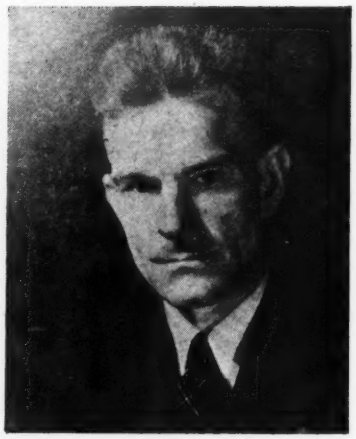
R. D. WYCKOFF

RALPH D. WYCKOFF graduated from Michigan State College in 1920 with a B.S. degree in Electrical Engineering. After several years in general power engineering, he joined the Electrical Instrument Section of the U. S. Bureau of Standards where he worked on precision-instrument test equipment from 1923 to 1925. From 1926 to 1929, Mr. Wyckoff was with the Geophysical Research Laboratory of the Marland Oil Company studying gravity measurement techniques, and from 1929 until the present date, he has been engaged by the Gulf Research and Development Company, initially to develop gravity pendulum equipment and, later, to study fluid flow and applications to reservoir engineering. From 1942 until the present date, he has been Chief of the Physics Division of Gulf.

Mr. Wyckoff is a member of the American Physical Society, American Geophysical Union, Society of Exploration Geophysicists, Institute of Radio Engineers, and the American Institute of Mining and Metallurgical Engineers

M. KING HUBBERT was trained at the University of Chicago during the period 1924 to 1931 in geology, physics and mathematics, receiving the degrees B.S., M.S., and Ph.D. During the summer of 1926 and for a year in 1927–1928 he worked as an assistant geologist for the Amerada Petroleum Corporation, and was engaged in both geological mapping and reflection and refraction seismic work. From 1931 to 1940 he taught structural and engineering geology and geophysics at Columbia University, and also was employed at various times as geophysicist for the Illinois Geological Survey, and Associate Geologist for the U.S.G.S.

He devoted two years during the war to studying world mineral resources for the Board of Economic Warfare. In October, 1943 he joined the Shell Oil Co., Inc. as research geophysicist and in June, 1945, assumed his present position of Associate Director of Shell's newly established Division of Exploration and Production Research.



M. KING HUBBERT

HAROLD C. BICKEL received the degree of B.S. in Electrical Engineering from Lehigh University in 1936. The next ten years were devoted to geophysical work for various subsidiaries of Standard Oil Company of New Jersey. The first year was spent doing seismic and gravity work in the States for the Carter Oil Co.; subsequently, one year each in Peru and Ecuador doing gravity work for International Petroleum Co., four years in Western Canada doing gravity and magnetic work for Imperial Oil Ltd., and three years in Colombia as Chief Geophysicist for the Tropical Oil Co. Early in 1947, he accepted his present position as Geophysicist with Seismograph Service Corporation in Tulsa.

Mr. Bickel is a member of the Society of Exploration Geophysicists, the American Association of Petroleum Geologists, Eta Kappa Nu, and Tau Beta Pi.

H. C. BICKEL

Photographs and biographies of contributors to this issue not appearing above have been published previously, as follows: EUGENE FROWE, Vol. XII, No. 1 (January 1947). KENNETH WATERS Vol. XII, No. 4 (October 1947).

THE SOCIETY ROUND TABLE

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C. A. Heiland, Chairman, Heiland Research Corp., 130 East Fifth Avenue, Denver 9, Colo.

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Ralph S. Jackson, Independent Exploration Co.
B. D. Lee, The Texas Company, Geophysical Lab.
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Paul D. Balbin, Stanolind Oil and Gas Co.
Lynn K. Lee, Pure Oil Co.
John H. Wilson, Independent Exploration Co., Abilene, Tex.

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Edward L. DeLoach, Atlantic Refining Co.
Thomas S. West, Blanco Oil Co.

Tulsa

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J. D. Eisler, Stanolind Oil & Gas Co.
A. J. Hintze, Phillips Petroleum Co., Bartlesville, Okla.
B. G. Swan, Continental Oil Co., Ponca City, Okla.

New Orleans

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L. I. Brown, The California Co.
B. H. Treybig, Jr., The Texas Co.

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George E. Wagoner, Chairman, The Carter Oil Co., Drawer 1739, Shreveport, La.
H. M. Buchner, The Carter Oil Co.
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Mississippi and Southeast

G. W. Gulmon, Chairman, Gulmon & Johns, Byrnes Bldg., Natchez, Miss.
Edwin D. Gaby, Geophysical Service, Inc., Jackson, Miss.
Booth B. Strange, Western Geophysical Co., Natchez, Miss.
J. H. Todd, The California Company, Brookhaven, Miss.

Rocky Mountain

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Gerald Burton, Shell Oil Company
M. D. Tucker, Stanolind Oil & Gas Company
M. J. Walczak, Atlantic Refining Company

Eastern States

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O. F. Ritzmann, The Golf Companies, Washington, D. C.
Milton Dobrin, Columbia University, New York.

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Arthur A. Brant, Toronto University, Toronto
J. H. Hodgson, Toronto University, Toronto
Hans Lundberg, Consulting Engineer, Toronto
J. T. Randell, Geo-Technical Development Co., Ltd., Toronto

Geophysical Case Histories Volume

Henry C. Cortes, *Chairman*, Magnolia Petroleum Co., Dallas
L. F. Athy, Continental Oil Co., Ponca City
A. B. Bryan, Carter Oil Co., Tulsa
Kenneth Burg, Geophysical Service, Inc., Dallas
E. D. Alcock, National Geophysical Co., Dallas
Dave P. Carlton, Humble Oil & Refining Co., Houston
O. C. Clifford, Atlantic Refining Co., Dallas
Ira Cram, Pure Oil Co., Chicago
E. L. DeGolyer, DeGolyer & MacNaughton, Dallas
C. Hewitt Dix, California Institute of Technology, Pasadena
Milton Dobrin, Naval Ordnance Laboratory, Washington
J. Brain Eby, Consulting Geologist, Houston
Frank Goldstone, Shell Oil Co., Houston
H. J. Hintze, Phillips Petroleum Co., Bartlesville

W. E. Hollingsworth, Sun Oil Co., Beaumont
J. W. Hoover, The California Co., New Orleans
J. C. Karcher, Continental Bldg., Dallas
Joseph A. Sharpe, C. H. Frost Gravimetric Surveys, Tulsa
Henry Salvatori, Western Geophysical Co., Los Angeles
Louis A. Scholl, The Texas Co., Houston
L. O. Seaman, Sinclair Prairie Oil Co., Tulsa
D. C. Skeels, Standard Oil Co., of N. J. New York
L. H. Waterfall, Union Oil Co. of California, Los Angeles
B. B. Weatherby, Geophysical Research Corp., Tulsa
Paul Weaver, Gulf Oil Corp., Houston
G. H. Westby, Seismograph Service Corp., Tulsa

Constitution and By-Laws

Wm. M. Rust, Jr , *Chairman*, Humble Oil & Refining Co., Houston
J. J. Jakosky, Union Oil Co., Los Angeles
G. E. Wagoner, Carter Oil Co., Shreveport
L. L. Nettleton, Gravity Meter Exploration Co., Houston
Henry C. Cortes, Magnolia Petroleum Co., Dallas
Cecil H. Green, Geophysical Service, Inc., Dallas
J. F. Gallie, Cabot Corp. Pampa, Tex.

Special Reviews

R. A. Geyer, *Chairman*, Humble Oil & Refining Co., Houston
Florence Robertson, St. Louis University, St. Louis
C. Hewitt Dix, California Institute of Technology, Pasadena
Milton B. Dobrin, Columbia Univ., New York
Noyes D. Smith, Shell Explor. & Prod. Lab., Houston
Henry R. Joesting, U. S. Geological Survey, Washington

Student Membership

James C. Menefee, *Chairman*, Magnolia Petroleum Co., Dallas
Ralph S. Jackson, Independent Exploration Co., Houston
Darrel S. Hughes, University of Texas, Austin
S. A. Lynch, Texas A. and M. College, Bryan
C. Hewitt Dix, California Institute of Technology, Pasadena
John H. Hodgson, University of Toronto, Toronto
V. L. Jones, University of Tulsa, Tulsa
Ralph C. Holmer, Colorado School of Mines, Golden

Best Paper Award

Roland F. Beers, *Chairman*, Geotechnical Corp., Dallas
W. T. Born, Geophysical Research Corp., Tulsa
Frank Goldstone, Shell Oil Co., Inc., Houston
M. King Hubbert, Shell Oil Co., Inc., Houston
Frederick E. Romberg, La Coste & Romberg, Austin
Paul Weaver, Gulf Oil Corp., Houston

Geophysical Education

James B. Macelwane, S.J., *Chairman*, St. Louis University, St. Louis, Mo.
Perry Byerly, University of California, Berkeley

Maurice Ewing, Columbia University, New York
Beno Gutenberg, California Institute of Technology, Pasadena
C. A. Heiland, Heiland Research Corp., Denver
M. King Hubbert, Shell Oil Co., Inc., Houston
D. C. Skeels, Standard Oil Co. of New Jersey, New York

Public Relations and Publicity

G. E. Wagoner, *Chairman*, Carter Oil Co., Shreveport
M. R. Budd, Hercules Powder Co., Wilmington, Del.
C. C. Campbell, Society of Exploration Geophysicists, Tulsa

Annual Survey of Geophysical Activity

E. A. Eckhardt, *Chairman*, Gulf Research & Development Co., Pittsburgh

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the President within thirty days. (Names of references appear in parentheses after the name of each nominee.)

ACTIVE

Richard Pete Akkerman (W. J. Osterhoudt, W. B. Lee Jr., J. E. McGee)
Wilton Wayland Andrews (H. G. Patrick, G. E. Bader, R. S. Duty)
Roland Krezdorn Blumberg (L. D. Leet, W. M. Rust Jr., M. C. Terry)
Frank Eugene Brown (C. H. McAlister, F. B. Smith, W. O. Novelly)
Robert Eugene Butler (E. J. Gemmill, W. T. Lea, E. G. Albright)
Harold Leslie Copeland (A. B. Bryan, W. E. Franks, W. C. Merritt)
Boyd Cornelison (J. M. Crawford, H. E. Banta, W. B. Lee Jr.)
Herbert Vinson Crowder (F. F. Reynolds, John D. Marr, H. H. Happel)
Clarence Gordon Daugherty Jr. (S. P. Weatherby, C. C. Zimmerman, H. W. McDonnold)
Allen Wendell Engle (W. G. Green, C. E. Duller, R. E. Fearon)
David LeCount Evans (G. E. Bader, V. J. Mercier)
Jackson Jefferson Flowers (Glenn E. Bader, M. M. Slotnick, J. A. Brooks Jr.)
John Tayman Geer (H. C. Cortes, H. E. Granberry, A. J. Oden)
John Kirby Godbey (D. H. Clewell, A. M. Eichelberger Jr., J. P. Minton)
Joseph Nunn Gragnon (P. J. Rudolph, W. L. Crawford, P. T. Rumsey)
George Herbert Harrington Jr. (J. H. Wilson, D. B. Campbell, T. I. Harkins)
Stanley Newton Heaps (C. G. Dahm, D. H. Clewell, J. P. Monton)
William Bayard Hercy Jr. (R. F. Beers, W. W. Newton, T. R. Shugart)
Odie Mouzon Holmes (C. D. Whitsitt, W. H. Taylor, J. B. Nichols)
Russell Edward Horn (P. E. Nash, J. C. Menefee, D. R. Dobyns)
Henry Allen Jackson (A. J. Oden, J. C. Menefee, D. R. Dobyns)
Hamilton McKee Johnson (Charles Duller, T. A. Manhart, George Reed)
Hal Joseph Jones (F. Goldstone, W. Hafner, R. D. Miller)
Lloyd Albert Kimes (W. J. Osterhoudt, W. H. Taylor, P. T. Rumsey)
J. Glenn Knowles (F. L. Bishop, C. H. Green, E. V. McCollum)
Barton Hamilton Kouri (G. D. Mitchell Jr., J. W. Byers, C. T. MacAllister)
Edward Arthur Krieg Jr. (Sidney Schafer, A. L. Ladner, Jack Ferguson)
John Edward Lee Jr. (L. F. Guseman, L. G. Cornish, R. H. Dausman)
Nathan Lowenstein (Mark C. Malamphy)

Gordon McLeod Mace Jr. (A. B. Hamil, R. W. Upshaw, W. H. Taylor)
Raymond Jules Maillet (E. G. Leonardon, J. C. Legrand, E. F. Stratton)
Ralph Willard Mann (W. M. Rust Jr., M. C. Terry, W. D. Mounce)
Joseph Hanford McCoy (E. D. Williams, D. B. Winfrey, L. O. Seaman)
Herbert Elmer Oowen (Norman Ricker, C. E. Edmonson, F. G. Boucher)
Gordon Lyall Paver (M. C. Malamphy, H. Shaw, Richard Davies)
Wayne A. Phares (C. H. Gerdes, B. W. Sorge, T. K. Bowles—*non-member*)
Charles Wesley Porter (E. H. Vallat, John W. Mathews)
William Addison Keeves (Paul Farren, J. A. Gillin, E. D. Alcock)
Robert Ernest Rettger (H. W. Rose, W. E. Hollingsworth, D. M. Collingwood)
Price Edgar Roberts (L. J. Peters, H. C. Moore, L. W. Gardner)
Arthur Elden Smith (W. Hafner, L. K. Mower, R. D. Miller)
Herbert Creston Smith (F. F. Reynolds, J. D. Marr, R. R. Rosenkrans)
Gilbert Swift (C. E. Duller, R. E. Fearon, W. G. Green)
Henry Leonard Swords (John Sloat, Henry Salvatori, Sidon Harris)
Harvey Louis Voelker (M. S. Morrison, H. G. Patrick, H. V. Goss)
Robert Patterson Warren (D. P. Carlton, J. E. LaRue, W. M. Rust, Jr.)
Evan Watts (A. J. Oden, H. E. Granberry, J. C. Menefee)
Donald Fessenden Weekes (C. S. Sharp, O. S. Petty, Van A. Petty, Jr.)
James Monroe Wilson (J. A. Lester, Rex H. White, P. E. Nash)
William Jacques Yost (Henry Cortes, J. P. Minton, D. H. Clewell)

ASSOCIATE

Kenneth Edward Andrews (K. H. Waters, E. D. Alcock, Paul Farren)
Ralph Deering Bartow (E. J. Handley, Leland Jones, Opie Dimmick)
Charles Edward Carlberg (J. W. Peters, W. B. Roper, H. E. Granberry)
Gordon Dwain Cloepfil (C. H. Green, Fred Agnich, W. P. Harvey)
John Cameron Donley (Sidon Harris, P. H. Ledyard, R. H. Dana)
Hugh Patrick Downey (Charles MacAllister, C. S. Sharp, John Byers)
Louis Franklin (L. L. Nettleton, J. L. Adler, L. W. Blau)
Kenneth Edgar Gibbs (Frank Ittner, J. E. Stones, L. B. Trombla)
Oswald F. Giddens (R. L. Lay, F. R. Coryn, C. R. Wallace)
Quinlivan Hayes (W. B. Roper, H. E. Granberry, J. W. Peters)
Hans Henry Helley (Sidon Harris, P. H. Ledyard, R. H. Dana)
Earl Richard Holm (W. P. Harvey, C. H. Green, Fred Agnich)
Robert Samuel Horner (W. T. Born, Dan Silverman, C. L. Brownlow)
Elvie Eugene Jeffcoat (E. G. Albright, L. B. Park, Victor Bychok)
Harold Eugene Kennett (E. V. McCollum, Craig Ferris, T. G. Arnold)
Jeff Edwin Miller, Jr. (M. P. Jones, J. W. Horn, R. W. Carson)
William Vernon Oakes (H. D. Marshall, C. J. Donnally, Dean Walling)
Jack Robertshaw (J. C. Templeton, V. L. Sigman, S. P. Hutton)
Maurice Glen Smith (P. P. Gaby, R. C. Dunlap, Jr., C. F. Van Beveren)
Arthur Walter Spreckels (C. C. Zimmerman, H. W. McDonnold, S. P. Weatherby)
Jack Gordon Swanson (M. C. Kelsey, H. H. Moody, J. F. Rollins)
Henry Clay Towles, Jr. (M. P. Jones, J. W. Horn, R. W. Carson)
Robert Walls (C. H. Acheson)
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Gertrude Riebold Whiting (H. D. Marshall, C. J. Donnally, W. E. Strangman)
Joe Richard Wier (C. J. Roy)

STUDENT

Surendra Raojibhai Amin (W. W. Longley)
Dewey Douglas Bowling (Ralph C. Holmer)

Paul Edward Samon (R. H. Cowie)
Charles Robert Holmes (J. B. Macelwane, Florence Robertson)
Carl Kisslinger (J. B. Macelwane, Florence Robertson)
Robert Joseph Koenig (J. B. Macelwane, Victor Blum, Florence Robertson)
Fred Edward Moore (W. W. Longley)
William Lewis Roever (R. C. Holmer)
Sylvester Martin Shelton (P. E. Narvarte, B. C. Tucker)
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TRANSFER FROM ASSOCIATE TO ACTIVE

Robert Beresford
Eugene J. Cronin
J. Byron Jones
A. P. Mehringer
Charles W. Oliphant
E. A. Pielemeier
I. W. Russek
Ivan B. Scherb
Douglas H. Smith
Mark Whelan
James Neff Wilson

TRANSFER FROM STUDENT TO ACTIVE

Ralph T. Duffner

TRANSFER FROM STUDENT TO ASSOCIATE

DeWitt C. Van Siclen

REINSTATEMENT TO ACTIVE MEMBERSHIP

Carol Gwyn Rosaire, Sr.
Burton Donald Lee
George Washington Martin
Samuel Camp Stoneham

RESIGNATION

K. A. Browning
Everett Filley Jr.
John P. Hammett
LeRoy Leonard Hammial
R. L. Kelsch
Howard L. Kipfer
Bernal M. Meador
C. E. Myers
Frederick A. Tompkins

ABSTRACTS OF PAPERS READ AT THE PACIFIC COAST JOINT MEETING

November 6–7, 1947

CORRELATION IN CALIFORNIA

John Sloat, Union Oil Company, Bakersfield, California.

In this opening paper the fundamental problem of cause and effect of seismic reflections is briefly discussed. An attempt is made to define record character and the factors which affect character correlation. The question of the recognition of geologic members from seismic records, and correlation of these members is considered. It is argued that several known beds can be identified and correlated over considerable area. The question of recognition of the Basement reflection is discussed in detail, with records showing the appearance of this member at numerous points where the Basement has been cored and where adequate velocity control is available.

SIGNIFICANCE OF THE "A" REFLECTION OF FRESNO AND MADERA COUNTIES, CALIFORNIA

Loring V. Snedden, The Texas Company, Bakersfield, California.

A reflection has been obtained extending over a large area in the northern San Joaquin Valley. Because of its unknown origin when first observed, it was designated the "A" reflection. Subsequent work has demonstrated that this reflection originates from a conglomerate bed in the Cretaceous. Due

to its widespread areal extent and the reliability with which it may be traced, this reflection makes possible a correlation of widely scattered Cretaceous sections which otherwise would be difficult to correlate.

COMPLICATIONS IN BASEMENT REFLECTION CORRELATION

W. D. Cortright, Tide Water Associated Oil Company, Bakersfield, California.

The purpose of this paper is to show by illustration how the top of Basement reflection character correlation may be misleading, and to suggest some geologic conditions which may have a bearing on the situation. Local migration vertically of the typical Basement reflection, although a disturbing factor, does not prevent the extended use of this reflection band as a basis for mapping the basement configuration.

CORRELATION POSSIBILITIES IN THE SACRAMENTO VALLEY

Kenneth S. Cohick, Shell Oil Company, Inc., Sacramento, California.

Exhibited seismograms show probable reflection correlation over a rather ideal correlation area in the Sacramento Valley. Attempts to extend the correlation beyond this area are discussed.

EXAMPLES OF SEISMIC SECTIONS ACROSS KNOWN FAULTS

O. F. Van Beveren and M. G. Smith, Standard Oil Company of California, Bakersfield, California.

Several suites of seismograph records and cross-sections across known faults are presented. Seismic data sometimes do and sometimes do not reveal the faulting.

STRATEGIC CORRELATION VS. MULTIPLE REFLECTIONS

Cecil E. Reel, Superior Oil Company, Los Angeles, California.

In the San Joaquin Valley an example is shown where no deep structure is indicated by the correlation on the deep beds. However, in this area there is a good reversal in the upper beds. Multiple reflections from the reversing shallow beds could be misleading and cause a misinterpretation in the deep zone.

NOTES ON THE MIGRATION OF STEEP DIPS WITH SPECIAL REFERENCE TO CURVED PATHS

E. J. Handley, Century Geophysical Corporation, Tulsa, Oklahoma.

Computing procedures are outlined to be followed in areas of steep dips. Some practical procedures are suggested to be used in areas of steep dips where a linear increase of "instantaneous" or true velocity with depth holds to an acceptable approximation.

CORRELATION OF REFLECTIONS WITH ELECTRICAL AND GEOLOGICAL LOGS

C. Hewitt Dix, United Geophysical Company, Pasadena, California.

By examining the pulse shapes on well velocity records in a case where the transients were particularly short and well defined, an average pulse shape was established. Using the electrical log and the geological log, major contacts were established. From the well's interval velocity results it was decided whether the velocity increased or decreased with increasing depth at the main sharp contacts. Using the well's time-depth data, the average pulse-shape, the depths of contacts, and assigning direct (positive) character to the pulse when the velocity increases downwards and inverted (negative) character when the velocity decreases downwards, a synthetic record was made. This synthetic record shows a remarkable resemblance to near-by records actually shot. The timing is essentially correct and the reflections are correctly identified as positive and negative on the synthetic record. Inspection of the average pulse shows in this case, a direct first part, followed by a second part which is reflected from the ground surface.

Since every reflection on the present synthetic record (and on the actual records) appears as a doublet, only the first parts are to be correlated simply and directly with geological contacts. This is

also true of the basement, the second part of the basement doublet plotting well below the basement top.

The bearing of these matters on the problem of correlating from record to record is quite evident since the term "character" is made to refer to a really characteristic shape in the pulse.

GEOPHYSICAL HISTORY OF THE WILMINGTON OIL FIELD, LOS ANGELES BASIN, CALIFORNIA

N. R. Shade, General Petroleum Corporation, Los Angeles, California.

This paper, with maps, describes the 1936 seismograph survey and results obtained over Wilmington Oil Field prior to the discovery of oil by drilling. A map made from data obtained by drilling in the development of the field is shown for comparison. There is very good agreement between the 1936 seismograph map and the 1946 map made from well data. The field methods and the methods of presentation of data are described, and examples of seismic records and sections are shown.

CASE HISTORY OF McDONALD ISLAND

Phil P. Gaby and A. J. Solari, Standard Oil Company of California, San Francisco, California.

The discovery well at McDonald Island was located on the basis of a reflection seismograph survey made in the Fall of 1935, extending through January, 1936. The "lead" was picked up by a routine reconnaissance seismograph program. The area, situated in the Sacramento River delta, has a surface cover of silt, peat and decayed vegetation. Geophysical problems peculiar to that type of region are discussed, and the use of buried detectors is also briefly mentioned. The seismograph contour map, as prepared prior to drilling of the discovery well, is shown and compared to present contour maps based on well correlation. Probable causes for the differences between these two maps are discussed.

ON THE PENETRATION OF ALTERNATING ELECTRICAL CURRENTS INTO THE GROUND

G. Potapenko, California Institute of Technology, Pasadena, California.

The theory of penetration of an alternating electric current into the ground is relatively simple if limited to the case of two horizontal beds, provided the spread between the current carrying electrodes is much larger than the depth to the boundary plane between the beds. In this simple case the penetration depends mainly upon the frequency of current v, and upon the ratio of the resistivity ρ of the lower bed to the resistivity ρ_0 of the upper bed.

Using the data available, a diagram has been constructed which indicates for each v and each $(\rho-\rho_0)/(\rho+\rho_0)$ the two critical depth values: D_m and D_n $(D_m<D_n)$, defined as follows. When the depth h to the boundary plane is smaller than D_m, the skin-effect is negligible, the lower bed can be easily detected, and h can be accurately determined. When $D_m<h<D_n$, the lower bed can be detected but h cannot at present be determined accurately due to shortcomings of the theory. Finally, when $h>D_n$, the skin-effect is so large that the lower bed cannot be detected, D_n may, therefore, be taken as a measure of the depth of penetration, i.e. the maximum depth attainable in resistivity prospecting. D_m, on the other hand, must be used at present in place of D_n when quantitative interpreting is needed. In the case of many horizontal layers, one of which may be chosen as a marker bed, the depth of penetration may be estimated by considering the layers above the marker as a single layer of an equivalent resistivity ρ'. This ρ' may be approximately calculated using a formula suggested by Hummel for the case of electric sounding.

AN IMPROVED METHOD OF LAND SURVEYING FOR USE IN BRUSH COVERED AREAS

Kenneth H. Waters, National Geophysical Co., Inc., Dallas, Texas.

A method is presented by which surveying in brush covered areas can be conducted above the tops of the trees, thus eliminating costly brush cutting. The technique and equipment is described for making the traverse across such country.

WELL VELOCITY SHOOTING IN CALIFORNIA

Robert J. Wells, Richfield Oil Corporation, Bakersfield, California.

Well velocity shooting stands as probably the most direct way of getting seismic velocity information at the present time. Sources of error and approximate magnitudes of errors are summarized, and the disturbing and misleading effects of impulses transmitted down the well geophone cable are discussed in detail. Several examples of the latter phenomenon in California are shown, and analyses are made indicating the probable path the energy travels from the shot to the cable, and thence down the cable to the geophone. The attenuation and velocity of the wave down the cable are evaluated, and the effect of cable transmitted energy in using multiple geophones on the same cable is discussed. The paper concludes with a rough evaluation of accuracy requirements for usable well velocity data, and suggests refinements in techniques to achieve these accuracies, and, in particular, to eliminate or reduce the uncertainties introduced by cable-borne energy.

NOTE ON SHOOTING IN A WELL TO DETERMINE VELOCITY

Robert Dyk, General Petroleum Corporation, Bakersfield, California.

An example of a velocity survey is shown where explosive charges were placed in the well being surveyed, and the energy received by surface geophones was recorded. The field procedure is described and the advantages of this method over the conventional technique are discussed.

THREE DIMENSIONAL CONTROL AND CALCULATIONS IN SEISMIC DIP WORK

E. J. Handley, Century Geophysical Corporation, Tulsa, Oklahoma.

The differences between true dip components and apparent dip components are discussed, and their relationship is studied as a function of the magnitude of true dip, and of the angle between the directions of the components and the true dip. For dips that are too large it is shown that dip vectors should be used as dip gradients, with lengths inversely proportional to the tangents of their respective dip angles. In this manner the lengths of the vectors become horizontal contour intervals, which is of considerable value in interpretation. A universal true dip chart is described for determining from two dip components the magnitude and direction of true dip and the length of the gradient vector.

PAPERS READ AT MEETINGS OF THE LOCAL SECTIONS

DALLAS

November 4, 1947:

Resume of Regulations of Seismic Operations off the Texas Gulf Coast. Paul Nash, Magnolia Petroleum Company.

Offshore Operating Regulations in California. Kenneth Burg, Geophysical Service, Inc.

December 8, 1947:

Case History, Block 31, Crane County. Lee B. Park, Atlantic Refining Company.

January 12, 1948:

Case History, Apache Field, Caddo County, Oklahoma. F. R. Coryn, The Texas Company.

February 8, 1948:

An Improved Method of Land Surveying for Use in Brush Covered Areas. K. H. Waters, National Geophysical Company.

March 9, 1948:

The Geophysics and Geology of the Discovery of the Esperson Dome. W. L. Day, General Crude Oil Company.

HOUSTON

January 16, 1948:

The Geophysics and Geology of the Discovery of the Esperson Dome. Wallace C. Thompson, General Crude Oil Company.

TULSA

December 11, 1947:

Airborne Magnetic Instruments. John Hidy, Frost Geophysical Corportaion.

January 8, 1948:

Geophysical Survey of Haynesville (Texas) Salt Dome by Telluric Current Measurements. E. G. Leonardon, Geolectric Prospecting Company.

February 12, 1948:

Case History of Apache Field, Caddo County. F. R. Coryn, The Texas Company.

March 11, 1948:

Illustrated talks on cold weather and water operations:
Ft. Norman Area of Northern Canada. Marvin Romberg, The Carter Oil Company.
Southern Canada. E. Jack Handley, Century Geophysical Corporation.
Continental Shelf. D. P. Carlton, Humble Oil and Refining Company. Dan Silverman, Stanolind Oil and Gas Company.

March 8, 1948: (Joint meeting with Tulsa Geological Society)

Radio Activity and Petroleum Geology. Clark Goodman, Massachusetts Institute of Technology

COLORADO SCHOOL OF MINES SOCIETY OF STUDENT GEOPHYSICISTS

February 5, 1948:

Research as a Career. T. W. Nelson, Magnolia Petroleum Company.
Well Logging. James Morris, Pure Oil Company.

ANNOUNCEMENTS

INTERNATIONAL GEOLOGICAL CONGRESS

XVIII Session—Great Britain, 1948

A preliminary announcement of the XVIII Session of the International Geological Congress to be held in London August 25 to September 1, 1948 was published in the July, 1947 issue of GEOPHYSICS. Subsequently, the following additional information has been received.

The meetings of the Congress will be held in the Royal Albert Hall, the Lecture Theaters of the Royal Geographical Society, and the Imperial College of Science and Technology.

The list of subjects to be discussed at the Sectional Meetings of the Congress is as follows:

1. Problems of Geochemistry.
2. Metasomatic Processes in Metamorphism.
3. Rhythm in Sedimentation.
4. The Geological Results of Applied Geophysics.
5. The Geology of Petroleum.
6. The Geology, Paragenesis and Reserves of the Ores of Lead and Zinc.
7. The Geology of Sea and Ocean Floors.
8. The Pliocene-Pleistocene Boundary.
9. Faunal and Floral Facies and Zonal Correlation.
10. The Correlation of Continental Vertebrate-bearing Rocks.

11. Earth Movements and Organic Evolution.
12. Other Subjects.

Problems of African geology, selected palaeontological topics, and discussions on the mineralogy and geology of clays will also be considered.

In addition to the 32 excursions previously announced, five more are being organized, three to visit East Anglia and Jersey, and two to demonstrate the general geology of Scotland, and the hydrogeology of England and Wales. There will also be a series of daily excursions and visits to scientific institutions centered on London between August 22 and September 3.

Communications should be addressed to the:

General Secretaries
XVIII Session International Geological Congress
Geological Survey and Museum
Exhibition Road
London, S. W. 7

GEOPHYSICAL EXHIBITS IN THE HALL OF SCIENCE, INTERNATIONAL PETROLEUM EXPOSITION, TULSA

The International Petroleum Exposition will be held in Tulsa the week of May 15–22. As part of the Exposition, a large building has been reserved for scientific exhibits, which will be called the Hall of Science. Dr. B. B. Weatherby has been appointed General Chairman of the Hall of Science, and he has appointed chairmen of committees covering geology, geophysics, production, refining, transportation, etc. Each of these committees will be responsible for providing scientific exhibits in their particular fields. The exhibits in the Hall of Science will be arranged in a natural order, leading from the geological exhibits through geophysical, drilling, production, refining, etc.

The purpose of the Hall of Science is to provide educational exhibits that will illustrate principles of the actual geological, geophysical and production operations in the industry. Included, in addition to the scientific exhibits illustrating principles, will be commercial exhibits illustrating actual commercial instruments and equipments. However, the accent will be upon educational exhibits rather than commercial equipment.

I have been appointed Chairman of the Geophysical Committee and have on the Committee Mr. W. T. Born of Geophysical Research Corp., Dr. A. B. Bryan of Carter Oil Co., Dr. J. E. Hawkins of the Seismograph Service Corp., Dr. G. D. Lambert of Shell Oil Co., Dr. J. P. Minton of Magnolia Petroleum Co., Dr. R. L. Doan of Phillips Petroleum Co., Dr. L. J. Peters of the Gulf Research and Development Co., and Mr. L. Watt Stinson of Radio Station KVOO. This Committee, with the assistance of the oil companies and geophysical instrument and service companies, will design and construct exhibits, and provide displays of scientific instruments. It is our hope to provide a scientific exhibit covering the field of geophysics which will reflect credit upon the industry.

The exhibits which are planned for the geophysical portion of the Hall of Science are divided into several categories, including seismic, gravity, magnetic, electric, surveying, logging and miscellaneous. Under the seismic group will be displays illustrating the principle of the propagation of seismic waves through the earth and the manner in which the waves are initiated and recorded, typical seismic records, displays illustrating the extreme sensitivity of seismic instruments, displays of seismic instruments and equipment, including cutaway models and partial assemblies, and displays illustrating the methods of operation in offshore seismic prospecting.

In the field of gravity measurements will be exhibits illustrating the principle of the determination of geological structure by gravity measurements. These will point out the effect of density of rocks upon the value of gravity at a point on the surface of the earth, and the type of response observed on a gravimeter when a traverse is made across a structure. There will be displays of gravimeters and models illustrating the processes of operation of gravimeters.

Magnetic measurements will be illustrated by displays showing the magnetic effect of rocks and

the type of response observed on a magnetometer when a traverse is made over a structure. Models will be shown illustrating different types of magnetometers, and a complete display of the airborne magnetometer will be shown.

Although the electrical method of geophysical prospecting is of minor commercial importance at the present time, it is one of the oldest methods, and its principle of operation will be illustrated by suitable displays.

Since surveying is such an important part of geophysical operations, considerable effort will be devoted to displays in this field. These will include displays of conventional optical surveying instruments, mechanical instruments, such as the Odograph and the elevation meter, and electrical methods of surveying, including radar and radio range measuring systems such as Decca, Raydist, etc.

The logging group of exhibits will be prepared in conjunction with the Production Committee and will include demonstrations of the principles of operation of electrical and gamma ray logging.

There will be a miscellaneous group of exhibits which will provide information in the way of numbers of geophysical crews, their locations, the importance of each of the several methods and the effectiveness of geophysical operations.

I am sure that the material to be displayed at this Exposition will be of interest to everyone, including those who are actively engaged in geophysical work. I urge all the members of the Society of Exploration Geophysicists to attempt, if possible, to visit the International Petroleum Exposition, and particularly the Hall of Science, and to urge all their friends who do visit the Exposition to see the scientific exhibits.

DANIEL SILVERMAN, *Chairman*
Geophysical Committee,
Hall of Science

RECOMMENDED AMENDMENTS TO THE CONSTITUTION AND BYLAWS
REPORT OF THE CONSTITUTION AND BYLAWS COMMITTEE

The Constitution and Bylaws Committee of the Society of Exploration Geophysicists held a meeting in Dr. Rust's office on January 9, 1948 to consider the various objections raised to various provisions in the revised Constitution. While all revisions were approved by a large majority, the objections raised by a small minority appeared to the Committee to be so carefully considered that the Committee is of the opinion that amendments meeting these objections should be submitted to the membership of the Society.

The Committee respectfully submits the following list of amendments for consideration by the Council of the Society of Exploration Geophysicists at the annual meeting in Denver in April 1948.

AMENDMENTS

Amendment A. The membership class of Fellow is to be abolished and all references in the Constitution and Bylaws to Fellows shall be deleted. Any renumbering of sections necessitated by such deletion will be made.

Amendment B. Article III, Section 9, for the words "may not publish his affiliation with the Society," substitute the words "in publishing his affiliation with the Society shall clearly indicate his grade of membership."

Amendment C. Article IV, Section 1, delete Sections 1 and 2 and substitute therefor "Membership of any class shall be contingent upon conformance with the established principles of professional ethics." In Bylaws Article III, Section 3, delete second sentence and in Bylaws Article VI, Section 4, delete "shall be found guilty of a violation of the Code of Ethics of this Society, or."

Amendment D. Article VIII, Section 1, before the words "District Representatives" delete the word "the" and add "and all elected." Cancel "and the chairmen of all standing committees." Article VIII, Section 3, at the end add "All committee chairmen shall attend this meeting, but, as chairmen, shall have no vote."

Amendment E. Article XII, Section 1, at end add "Council may designate Districts outside the area of the continental United States."

Amendment F. Cancel Article XII, Section 2.

Amendment G. Renumber Article XII, Section 3 as Section 2 and before the words "one District Representative," insert the words "for each seventy-five Active Members of the Society, who are not members of a Local Section,".

Amendment H. Amend Bylaws Article III, Section 5 by adding at the end "In the case of applicants for Student Membership, publication is not required. The Student Member shall be pronounced elected when approved by the Secretary-Treasurer."

Amendment I. Article IV, Section 3, delete the entire section. Renumber Sections 4 and 5, and in Section 2, after the word "Active" add the words "or Associate."

W. M. Rust, Jr., *Chairman*

PERSONAL ITEMS

(Members are requested to forward material for inclusion in PERSONAL ITEMS to C. C. Campbell, P. O. Box 1614, Tulsa 1, Oklahoma)

L. F. IVANHOE, Geophysicist for Venezuelan Atlantic Refining Company, has transferred from Caracas, Venezuela to Box 117, Inwood Iowa.

O. C. LESTER, JR. has resigned his position as Supervisor of Geophysics for Amerada Petroleum Corporation. He now lists his position as "Oregon Farmer in fact, if not in experience." Address: Route 1, Box 326, Aurora, Oregon.

JOHN M. LOHSE resigned from the Geophysics Research Department of Humble Oil and Refining Company to become Research Engineer at the supersonic wind tunnel and combustion laboratory on guided missiles project. He may be addressed at 128 W. Jewel Ave., Longview, Texas, or in care of Consolidated-Vultee Aircraft Corp., Lone Star Laboratory, Daingerfield, Texas.

DR. C. HEWITT DIX is now an Associate Professor of Geophysics at the California Institute of Technology in Pasadena.

CHARLES H. DRESBACH, Formerly Assistant Manager and Chief Geologist, became General Agent of the Colombian Gulf Oil Company with headquarters in Bogota, Colombia, effective February 1st. His last domestic assignment was with the Western Gulf Oil Company; his years of service with various Gulf Companies totalling sixteen. He succeeds Major Harry G. Davis, retired.

JOHN J. BABB, formerly Party Chief with Geophysical Service Inc., is now associated with Delta Exploration Company, Inc., Jackson, Mississippi.

L. M. HUBBY was recently transferred from Party Chief to the Geophysical Research Laboratory of The Texas Company at Houston in the position of Electrical Engineer.

SHERWIN F. KELLY, President of Sherwin F. Kelly Geophysical Services, Inc. of Wilmington, Delaware, and Geophysical Explorations Ltd. of Toronto, Canada, has recently returned from operations in various mining properties in Peru and Bolivia.

J. A. LEGGE, JR., P. O. Box 1310, Fairbanks Alaska, is starting on his fourth season as geophysical supervisor of Naval Petroleum Reserve No. 4.

DR. ANDREW M. MACMAHON, owner, announces the completion of the new Southwestern Physical Laboratories at 2301 West Alabama Avenue, Houston 6, Texas. Work was completed in September 1947 on the labs which are designed for general consulting and development work.

MRS. ETHEL WARD MCLEMORE is at present devoting her time to the study and completion of problems of interpretation, and plans to publish the results of this research.

BEN S. MELTON, formerly with the National Geophysical Company, is now Senior Engineer and Staff Member of the Applied Physics Laboratory at Johns Hopkins University. His address is 8621 Georgia Avenue, Silver Spring, Maryland.

ROBERT L. MIMS, and Active Member of the Society, is taking graduate courses in Physics, Mathematics, and Geology at the University of Texas.

W. H. MYERS, party chief with United Geophysical Company, is temporarily stationed in San Juan, Puerto Rico doing seismic prospecting for oil on land and in water. His address is Box 63, San Juan, Puerto Rico.

ROY WARD PEARCE is now Geologist with Phillips Petroleum Company, P. O. Drawer 1729,

Shreveport, Louisiana. He spent six years with the Socony-Vacuum Oil Company of Venezuela in that country.

ROBERT R. PHILLIPS, Seismologist and Engineer, opened a consulting office in October 1947. He specializes in Seismology (seismic review work) and Photogrammetry (controlled mapping and terrain studies). His address is 218 N. Congress St., Jackson, Mississippi.

DR. T. C. RICHARDS, Geophysicist with Anglo-Iranian Oil Company Ltd., Britannic House, Finsbury Circus, London E.C. 2, was formerly in Nassau with the Anglo-Bahamian Petroleum Company.

H. LEROY SCHARON recently left Section of Geophysics, U. S. Geological Survey, to accept the following: Assistant professorship of geology and geophysics at Washington University, St. Louis, and consulting geophysicist at the St. Louis Smelting and Refining Company.

ARNOLD J. F. SIEGERT accepted an appointment as professor of physics at Northwestern University, Evanston, Illinois in the Fall of 1947.

RAY W. WALLING was promoted from Assistant Division Seismograph Supervisor in Fort Worth to Division Seismograph Supervisor for Stanolind Oil and Gas Company in Casper, Wyoming, on January 1, 1948.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS
CONSTITUTION AND BYLAWS

(As amended to April 1947)

Article I. Name

Section 1. This Society shall be called the "Society of Exploration Geophysicists."

Article II. Object

Section 1. The objects of this Society shall be to promote the science of geophysics especially as it relates to exploration and research, to foster the common scientific interests of geophysicists, and to maintain a high professional standing among its members.

Article III. Membership

Section 1. The membership of this Society shall consist of persons elected and qualified in accordance with the Constitution and bylaws of this Society at the time of such election.

Section 2. The membership of this Society shall consist of Honorary Members, Fellows, Active Members, Associate Members, and Student Members.

Section 3. To be eligible to election to Honorary Membership a person shall, in the unanimous opinion of the Standing Committee on Honors and Awards and the Council, have made a distinguished contribution to geophysics or a related field which warrants exceptional recognition.

Section 4. To be eligible to election as a Fellow, a person shall, in the unanimous opinion of the Standing Committee on Honors and Awards and the Council, have done outstanding work in geophysics or a related field and shall have been an Active Member in good standing for ten or more years or have been an elected officer of the Society.

Section 5. To be eligible to election to Active Membership an applicant must have been actively engaged in practicing or teaching geophysics or a related field for not less than eight years (up to four years as a student in a recognized college or university may be counted toward this total) of which at least three years must have involved work of a responsible nature calling for independent judgment and the application of geophysical or geological principles.

Section 6. To be eligible to election to Associate Membership, an applicant must be actively interested in geophysics.

Section 7. To be eligible to election to Student Membership an applicant must be a graduate or undergraduate student in good standing in residence at a recognized university or college.

Section 8. An Honorary Member, Fellow or Active Member shall enjoy all privileges of the Society. He shall be eligible to hold any office, to vote on all matters submitted to the membership, to petition the Council or Executive Committee on any matter, to sponsor applicants for membership and to publish his affiliation with the Society.

Section 9. An Associate Member or Student Member shall be entitled to attend the meetings of the Society, to receive its Journal and to purchase its publications, on the same terms as an Active Member. He shall have none of the other privileges of membership and may not publish his affil'ation with the Society. Student Membership shall terminate one year after the Student Member ceases to be enrolled at a recognized university or college.

Article IV. Code of Ethics

Section 1. All members of the Society shall subscribe to the following code of ethics.

Code of Ethics

That the dignity of his chosen profession may be maintained, it is the duty of every member of the Society

1. To carry on his professional work in a spirit of fairness to employees and contractors, fidelity to clients and employers, and devotion to high ideals of personal honor.

2. To refrain from associating himself with, or allowing the use of his name by, any enterprise of questionable character.

3. To treat as confidential his knowledge of the business affairs, geophysical or geological information, or technical processes of clients or employers when their interests require secrecy.

4. To inform a client or employer of any business connections, interests, or affiliations which might influence his judgment or impair the disinterested quality of his services.

5. To accept financial or other compensation for a particular service from one source only, except with the full knowledge and consent of all interested parties.

6. To advertise only in a dignified manner, to refrain from using any improper or questionable methods of soliciting professional work, and to decline to pay or to accept compensation for work secured by such improper or questionable methods.

7. To refrain from using unfair means to win professional advancement and to avoid unfairly injuring another geophysicist's chances to secure and hold employment.

8. To cooperate in building up the geophysical profession by the interchange of general information and experience with his fellow geophysicists and with students and also by contributions to the work of technical societies, schools of applied science, and the technical press.

9. To interest himself in the public welfare and to be ready to apply his special knowledge, skill, and training in the public behalf for the use and benefit of mankind.

SECTION 2. It shall be the duty of any member of the Society having cognizance of a violation of this Code of Ethics by any other member to report confidentially in writing the details of such violation to the President of the Society, who shall forward a copy of the report to all members of the Executive Committee for investigation. The President shall destroy the original report and shall under no circumstances divulge the name of the member making the report. The Executive Committee shall hold all information relating to the charge and their investigation in complete confidence until such time as they may agree unanimously upon the disciplinary action to be taken.

ARTICLE V

ELECTION, RESIGNATION AND EXPULSION OF MEMBERS

SECTION 1. The method of election to the various grades of membership shall be as set forth in the Bylaws.

SECTION 2. Any member in good standing may resign from the Society at any time as set forth in the Bylaws.

SECTION 3. Any member may for the good of the Society be suspended or expelled from the Society at any time as set forth in the Bylaws.

ARTICLE VI. OFFICERS

SECTION 1. The officers of the Society shall be a President, a Vice-President, a Secretary-Treasurer, and an Editor. Officers shall be elected in the manner prescribed in the Bylaws for a term of one year with the exception of the Editor, whose term shall be two years.

SECTION 2. Election of officers shall be by secret mail ballot. On the ballot shall be printed the nominees for each office arranged in alphabetical order.

SECTION 3. The Standing Committee on Nominations shall nominate, in the manner prescribed in the Bylaws, two candidates for each office to be filled. Further nominations may be made by petition as set forth in the Bylaws.

SECTION 4. The officers shall assume the duties of their respective offices immediately after the close of the Annual Meeting following their election.

SECTION 5. No officer shall be eligible for election to the same office for two consecutive terms.

SECTION 6. In case of a vacancy in any office, other than the President's, the Executive Committee shall select a successor to serve until the close of the annual meeting following this appointment.

Article VII. Duties of Officers

Section 1. The President shall be the presiding officer at all the meetings of the Society, shall take cognizance of the acts of the Society and of its officers, shall appoint such Standing Committees and special committees as are required for the purposes of the Society, and shall delegate members to represent the Society. He may, at his option, serve on, and may be chairman of, any committee. He shall prepare an address to be given before the members of the Society at the Annual Meeting.

Section 2. The Vice-President shall assume the office of President in case of a vacancy from any cause in that office and shall assume the duties of President in case of the absence or disability of the latter. He shall also be responsible for all National Meetings of the Society.

Section 3. The Secretary-Treasurer shall assume the duties of the President in case of the absence of both the President and Vice-President. He shall have charge of the financial affairs of the Society and shall annually submit reports as Secretary-Treasurer covering the fiscal year, which he shall arrange to have published in the next regular issue of the Journal of the Society. Under the direction of the Council, he shall arrange for the receipt and disbursal of all Society funds. He shall cause an audit to be prepared annually by a public accountant at the expense of the Society. He shall give a bond, and shall cause to be bonded, all employees to whom authority may be delegated to handle Society funds. The amount of such bonds shall be set by the Council and the expense shall be borne by the Society.

Section 4. The Editor shall be in charge of the editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the regular Society publication and for special publications, and may accept or reject material offered for publication. He may appoint associate, regional, and special editors.

Article VIII. Council

Section 1. The Council of the Society shall consist of the officers, the Past President, the Past Prior President, the District Representatives and the Chairmen of all Standing Committees.

Section 2. The Council shall be the governing body of the Society and subject to the provisions of the Constitution and Bylaws shall have full control and management of the affairs and funds of the Society.

Section 3. A joint meeting of the outgoing and incoming Councils shall be held at the call and under the Chairmanship of the newly elected President during or within seven days after the Annual Meeting of the Society. At this joint meeting the Councils shall hear reports from all Officers and Committees and review the activities of the Society for the past year. With the advice of the outgoing Council, the incoming Council shall conduct any necessary business and issue instructions or recommendations to any officer or committee, subject to the provisions of the Constitution and Bylaws.

Section 4. At the call of the President or a majority of the Council members, and after written notice to all Council members, the Council may meet at any time.

Section 5. A quorum at any meeting of the Council shall consist of six Council members.

Section 6. Unless otherwise provided by the Constitution, all actions by the Council shall require a majority vote of the members present.

Article IX. Executive Committee

Section 1. The Executive Committee shall consist of the President, the Vice-President, the Secretary-Treasurer, the Editor, and the Past President.

Section 2. When the Council is not in session the Executive Committee shall have full authority, subject only to prior instructions by the Council, to exercise all powers of the Council.

Section 3. All actions of the Executive Committee shall require a majority vote of all members of the Committee.

Section 4. The Executive Committee may vote on any matter either by mail or in person.

Article X. Meetings

Section 1. The Society shall hold at least one meeting of the members each year, this meeting to be known as the Annual Meeting. One session of this meeting shall be a Business Meeting, at which reports of the Officers and Committees shall be read and the results of the mail ballot for officers announced.

Section 2. The Annnal Meeting shall be held at a time and place designated by the Executive Committee.

Section 3. Additional meetings of the Society may be called by the Executive Committee.

Article XI. Local Sections

Section 1. Local sections, consisting of members of the Society and other persons engaged in geophysics or a related field residing within an appropriate distance of a central point, may be organized as provided in the Bylaws.

Section 2. Each local section shall assist in carrying out the objectives of the Society within the territory assigned to the section by the Council.

Section 3. Each local section shall have one district representative if among its members there are less than seventy-five Honorary Members, Fellows and Active Members of the Society in good standing, two district representatives if more than seventy-five and less than one hundred fifty, or three district representatives if more than one hundred fifty.

Section 4. The district representatives shall be elected from among the Honorary Members, Fellows and Active Members of the Society in good standing for terms stated and in the manner prescribed in the Bylaws and shall not be eligible for two consecutive terms.

Article XII. Districts

Section 1. The Council shall divide the area of the continental United States, not assigned to local sections, into not more than seven districts.

Section 2. No district shall contain less than fifty nor more than one hundred fifty active members of the Society, except that the area, not assigned to local sections, within a state shall all be within a single district.

Section 3. Each district shall have one district representative, who shall be appointed by the President for a term of one year expiring at the close of the Annual Meeting.

Article XIII. Affiliated Societies

Section 1. The Council may arrange for affiliation of the Society with any duly organized groups or societies.

Section 2. The terms of affiliation must provide that the Society shall have the right to dissolve such affiliation at any time, subject only to the payment of any sums it may legally owe the affiliated group or society.

Article XIV. Committees

Section 1. In addition to the Executive Committee, there shall be appointed Standing Committees to further the purposes of the Society.

Section 2. The duties of the Standing Committees and the method of their appointment shall be in accordance with the Bylaws.

Section 3. The President may at any time appoint Special Committees for such purposes as he may deem fit.

Section 4. The terms of all Special Committees shall expire at the close of the Annual Meeting following their appointment.

Article XV. Business Manager

Section 1. The Council may employ a Business Manager for the Society and pay him such salary and other compensations from the Society's funds as they deem advisable.

SECTION 2. The Business Manager shall provide a bond appropriate in amount, the cost to be borne by the Society.

SECTION 3. The Business Manager shall, under the supervision of the Secretary-Treasurer, perform such duties as the Council may assign him.

SECTION 4. The Council may discharge the Business Manager at any time.

ARTICLE XVI. REVIEW BY MEMBERS

SECTION 1. All acts of the Officers, Council, and Committees of the Society shall be subject to review by the members.

SECTION 2. Proposals to change any decision, policy or procedure of any Officer, the Council, or any Committee shall be submitted in writing to the President and signed by at least twenty-five Honorary and Active Members or Fellows in good standing.

SECTION 3. Upon receipt of such a petition with a sufficient number of valid signatures, the President shall advise the Council and the Officer or Committee involved.

SECTION 4. Should the Officer or Committee involved be unwilling to comply with the petition, it, together with a discussion by the proposer and the Officer or Committee involved, shall be published in the next issue of the Society's Journal.

SECTION 5. Within thirty days after publication in the Journal, the petition shall be submitted to the membership by mail ballot by the President. A majority of the ballots returned within thirty days after being mailed by the President shall be decisive. Should the vote favor the petition, it shall be complied with, within the limitations imposed by the Constitution and Bylaws, as promptly as practicable.

ARTICLE XVII. BYLAWS

SECTION 1. The Council shall make such Bylaws not in conflict with the Constitution, as it may deem necessary for the proper government of the Society. The Council may amend the Bylaws at the annual joint meeting by an affirmative vote of two-thirds of the members of the incoming Council present. All proposed amendments must, however, be published in the Society's Journal before being submitted to the Council.

ARTICLE XVIII. AMENDMENTS TO THE CONSTITUTION

SECTION 1. Amendments to this Constitution may be proposed by any ten members of the Society, by any Officer of the Society, or by a Constitutional Committee appointed by the President.

SECTION 2. Any proposed amendment shall be submitted to the President in time for publication in the Society's Journal prior to the Annual Meeting.

SECTION 3. At the annual joint meeting of the Council, all proposed amendments received since the previous annual meeting, shall be considered. Those receiving approval from a majority of the members of the incoming Council present shall be submitted by mail ballot, arranged by the Secretary-Treasurer, to the entire membership of the Society within sixty days. If a majority of the ballots returned within sixty days of their mailing favor the proposed amendment, it shall become effective at the expiration of this sixty days. All amendments shall be reported in the Society's Journal.

BYLAWS

ARTICLE I. PUBLICATIONS

SECTION 1. The Society shall publish a Journal entitled GEOPHYSICS.

SECTION 2. The Journal shall be published at intervals designated by the Executive Committee.

SECTION 3. All reports to the Society by its officers and committees shall be published in the Journal. All members of the Society shall be presumed to have due notice of all Society matters published in the Journal. Each issue shall contain a membership list of all Standing and Special Committees.

SECTION 4. Original papers, reviews, abstracts, note or letters containing information deemed by

the Editor to be of interest to the members of the Society shall be published in the Journal. The Editor shall be the sole judge of whether such material is to be published.

SECTION 5. The subscription rate of the Journal shall be $6.00 ($6.50 foreign) per year to non-members and $3.00 per year to members. The first $3.00 of the annual dues of each due paying member shall be set aside for the payment of his subscription to the Journal. Members of affiliated Societies shall be entitled to receive the Journal upon payment of a fee equivalent to the dues charged to an associate member.

SECTION 6. The Council may at its annual joint meeting authorize the printing of special publications to be financed and distributed in a manner approved by the Council.

ARTICLE II. ELECTION OF HONORARY MEMBERS AND FELLOWS

SECTION 1. The Standing Committee on Honors and Awards may submit to the President ninety days before the Annual Meeting the names of any person or persons they deem eligible to election as an Honorary Member or Fellow. Their report shall explain the basis of their recommendation.

SECTION 2. The President shall submit copies of any such reports to all members of the Council not less than sixty days before the Annual Meeting.

SECTION 3. The Council members shall consider all such reports and vote by mail thirty days before the Annual Meeting. Unanimous action by those voting shall be required to elect any person as an Honorary Member or a Fellow.

SECTION 4. In no year may the number of members proposed for election as Fellows exceed two per cent of the number of Active Members, nor may the total number of Fellows ever exceed ten per cent of the number of Active Members.

ARTICLE III. ELECTION OF ACTIVE, ASSOCIATE AND STUDENT MEMBERSHIP

SECTION 1. An applicant for election to Active, Associate or Student Membership shall submit to the Business Manager of the Society an application setting forth in detail his education and experience. The application shall list the names and present addresses of persons who can verify the statements given therein. It shall list not less than three Active Members, Honorary Members, or Fellows of the Society, in good standing who are personally acquainted with the training or experience of the applicant. This application shall be open to inspection at any time.

SECTION 2. The Executive Committee may waive the requirement of references from members of the Society for geographical or other reasons, if the applicant is otherwise eligible and furnishes other satisfactory references.

SECTION 3. The Business Manager shall write to all references for verification of the applicant's statements. The attention of the references shall be specifically called to the Society's Code of Ethics. All replies from references shall be considered confidential and shall not be disclosed except to the Executive Committee, without the references' prior written consent.

SECTION 4. The Business Manager, upon receipt of the replies from all references, shall submit to the Executive Committee the application and the replies from the references.

SECTION 5. Should the Executive Committee unanimously approve and sign the application, the applicant's name shall be published in the next regular issue of the Society's Journal for approval by the membership at large. If no objection to his election is received by the President within thirty days after this publication, he shall be pronounced elected. The Business Manager will notify the applicant.

SECTION 6. An applicant for membership, upon being notified in writing of his election, shall pay full dues for the current year and upon making payment shall receive a membership card and the regular Society publications for the year of entrance. Unless payment of dues is made within thirty days by those living within the continental United States and within ninety days by those living elsewhere, the Executive Committee may rescind the election of the applicant.

SECTION 7. An Associate or Student Member may seek transfer to Active Membership by supplying added information to show that he has become eligible to election to Active Membership. The transfer shall be handled in the same manner as election to Active Membership. The Standing Committee on Membership may of its own initiative secure the necessary added information and submit it to the Executive Committee.

Article IV. Dues

Section 1. Honorary members shall not be required to pay dues and shall receive the Journal and other publications without charge.

Section 2. The annual dues of an Active Member or Fellow of the Society shall be five dollars ($5.00), which includes the cost of one subscription to the Society's Journal.

Section 3. The annual dues of an Associate Member for not to exceed six years after election shall be four dollars ($4.00); thereafter, the annual dues of such Associate Member shall be five dollars ($5.00).

Section 4. The annual dues of a Student Member of the Society shall be three dollars ($3.00), which includes the cost of one subscription to the Society's Journal.

Section 5. Annual dues shall be payable in advance on January 1 of the calendar year. A bill shall be mailed to each Fellow, Active, Associate or Student Member before that date, stating the amount of annual dues and the penalty for default. The Society's Journal shall be withheld from members pending payment of dues, and Active Members or Fellows failing to pay by ten days prior to the Annual Meeting shall have their votes in the annual mail ballot disqualified. Members in arrears shall lose all privileges of membership until such arrears are met.

Article V. Resignation of Members

Section 1. Any member of the Society may resign at any time. Such resignation shall be submitted in writing to the Council.

Section 2. Any member who resigns under the provisions of Section 1 of this Article ceases to have any rights in the Society and ceases to incur further indebtedness to the Society.

Section 3. Any person who has ceased to be a member under Section 1 of this Article may be reinstated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member of the Society.

Article VI. Expulsion of Members

Section 1. Any member more than two years in arrears shall be dropped from the Society by the Executive Committee.

Section 2. Any member who is dropped under the provisions of Section 1 of this Article ceases to have any rights in the Society and ceases to incur further indebtedness to the Society.

Section 3. Any person who has ceased to be a member under Section 1 of this Article may be reinstated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member of the Society.

Section 4. Any member who, after being granted a hearing by the Executive Committee, shall be found guilty of a violation of the Code of Ethics of this Society or shall be found guilty of a violation of the established principles of professional ethics, or shall be found guilty of having made a false or misleading statement in his application for membership in the Society, shall be asked to resign from the Society by unanimous vote of the Executive Committee. The decision of the Executive Committee in all matters pertaining to the interpretation and execution of the provisions of this section shall be final.

Article VII. Election of Officers

Section 1. The Standing Committee on Nominations shall consist of the President, the Past President, and the Prior Past President.

Section 2. The Standing Committee on Nominations shall nominate two or more candidates for each office to be filled. They must secure the consent of all candidates nominated.

Section 3. The Standing Committee on Nominations must submit their ticket to the President in time for publication in the October issue of the Society's Journal.

Section 4. For six weeks after the mailing date of the October issue of the Society's Journal, nominations in writing, signed by at least twenty Honorary Members, Fellows or Active Members in

good standing and accompanied by the written consent of the candidate, may be submitted to the President.

SECTION 5. At the expiration of the aforesaid six weeks period, the Business Manager will prepare and mail to each member, eligible to vote, a ballot listing all candidates properly nominated for each office. The candidates shall be listed alphabetically. With each ballot, the Business Manager shall send an official envelope having the member's name typed on the back.

SECTION 6. Each member voting shall cast one vote for each officer and shall return his ballot to the Business Manager in the official envelope carrying on the outside the written signature of the member submitting the ballot. Only ballots so prepared by members in good standing, and received by the Business Manager at his officially recognized address not later than ten days prior to the Annual Meeting shall be valid. The Business Manager shall indicate which ballots are valid and shall deliver the ballots unopened to the Standing Committee on Nominations for counting. The Standing Committee on Nominations shall personally supervise the counting of the ballots prior to the Annual Business Meeting. The candidates receiving the greatest number of valid votes cast for an office shall be declared elected to that office. In case of a tie, the Standing Committee on Nominations shall decide by a secret vote which of the candidates shall be elected.

ARTICLE VIII. LOCAL SECTIONS

SECTION 1. Upon petition of twenty members in good standing residing within an appropriate distance of a central point, the Council may authorize the formation of a Local Section and assign a specific territory to the Local Section. The Council may decline to authorize the formation of a Local Section when in its judgment such an organization would not be compatible with the interests of the Society.

SECTION 2. In the organizing meeting of the Section, all members of the Society residing in the territory assigned by the Council to the Section shall be eligible to vote.

SECTION 3. The Section shall be known as "The (name of place) Section of the Society of Exploration Geophysicists."

SECTION 4. The principal work of a Section shall be the holding of regular meetings for the presentation and discussion of papers of interest to its members.

SECTION 5. The Section shall adopt Bylaws which must be approved by the Council of the Society and shall be consistent with the Constitution and Bylaws of the Society.

SECTION 6. The election of District Representatives by the Local Sections shall be by secret ballot. The term of office of a District Representative shall be two years; however, if the Section is entitled to more than one Representative, one of the Representatives elected at the establishment of the Section or added as the result of subsequent growth of the Section, shall be elected for a one year term if this is necessary to prevent the terms of all District Representatives from expiring simultaneously.

SECTION 7. District Representatives shall be elected at least three weeks prior to the Annual Meeting of the Society and shall take office at the close of the Annual Meeting.

SECTION 8. The Secretary of the Local Section shall submit to the Secretary-Treasurer of the Society a report of each meeting of the Local Section or its governing board within two weeks after the meeting. He shall submit to the Secretary-Treasurer of the Society the names of all officers and committee members within two weeks after their election or appointment.

SECTION 9. Any Local Section which for two consecutive years has among its membership fewer than twenty members in good standing of the Society shall automatically be dissolved by the Council at its annual joint meeting. The Council may at any time dissolve any Local Section for reasons it deems good and sufficient.

ARTICLE IX. FINANCES OF LOCAL SECTIONS

SECTION 1. The Society will pay the necessary operating expenses of a Local Section up to the sum of the following amounts: (a) $100.00 per year; (b) $50.00 per meeting up to four meetings per year; (c) $0.50 per member of the Society.

SECTION 2. The Treasurer of the Local Section shall forward, from time to time, his application for such portions of the sum provided in Section 1 as may be needed to the Secretary-Treasurer of the Society, who will arrange for the issuance of a check for the requested amount to the Treasurer of the Local Section.

SECTION 3. Prior to the Annual Meeting, the Treasurer of each Local Section shall transmit to the Secretary-Treasurer of the Society, for approval by the Council, an itemized statement of the expenditure of the funds received from the Society during the preceding calendar year.

SECTION 4. Allocations to a Local Section for the year in which it is established shall be in proportion to the fraction of the calendar year remaining.

SECTION 5. The Local Section may levy dues or raise funds in any other manner, subject to the approval of the Council. Payment of local dues shall, however, not be a prerequisite to participation in any activity financed wholly or in part with funds received from the Society.

ARTICLE X. STANDING COMMITTEES

SECTION 1. The Society shall have the following Standing Committees: (a) Standing Committee on Nominations; (b) Standing Committee on Membership; (c) Standing Committee on Honors and Awards; (d) Standing Committee on Publications; (e) Standing Committee on Program and Arrangements; (f) Standing Committee on Education; and (g) Standing Committee on Student Membership.

SECTION 2. Each Standing Committee shall have a chairman, appointed by the President unless otherwise specified in these Bylaws. The Chairman shall submit a report to the President of the Society at such intervals as the Chairman may deem advisable but at least quarterly. He shall submit to the Council at its annual joint meeting a report covering the activities of the Committee since the previous annual meeting.

SECTION 3. The Standing Committee on Nominations shall consist of the President who shall be chairman, the Past President, and the Past Prior President. Its duties shall be to nominate candidates for officers, to supervise counting the ballots and to declare the election of the officers as prescribed in Article VII of these Bylaws.

SECTION 4. The Standing Committee on Membership shall consist of three active members appointed for a period of one year by the President immediately following the Annual Meeting. One of the members appointed shall have been a member the preceding year. The Committee shall prescribe the manner of soliciting applicants for membership.

SECTION 5. The Standing Committee on Honors and Awards shall consist of five active members, none of whom shall have been members of the Society less than five years. The senior member of the Committee shall retire after the Annual Meeting. Vacancies shall be filled by the President. The Committee shall recommend candidates for election to Honorary Membership or Fellowship to the Council. The Committee shall recommend to the Council the establishment of Honors and Awards and shall recommend candidates for all established Honors and Awards of the Society to the Council.

SECTION 6. The Standing Committee on Publications shall consist of five active members who shall serve a two year term concurrent with the Editor and who shall be appointed by the Editor. The Committee shall have the duty of advising and assisting the Editor. The Editor shall appoint the Chairman of this Committee.

SECTION 7. The Standing Committee on Program and Arrangements shall consist of the Local Representatives plus three to ten additional active members or fellows appointed for a term of one year by the Vice-President, who shall be Chairman. The names of the members of the Committee shall be published in the July issue of the Society's Journal. The Committee shall have the duty of assisting the Vice-President in arranging and holding the Annual Meeting.

SECTION 8. The Standing Committee on Education shall consist of five active members appointed for one year by the President. The Committee shall promote effective geophysical education.

SECTION 9. The Standing Committee on Student Membership shall consist of five active members appointed for one year by the President. The Committee shall encourage the interest of students in geophysics and the Society.

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MEMBERSHIP LIST (APRIL, 1948)

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Clifton, R. L.
England, C. M.
Fort Sill
Jackson, Robert W.
Marlowe
Ervin, Lynn D.
Norman
Schriever, William
Oklahoma City
Beebe, B. W.
Campbell, D. B., Jr.
Dunn, George V.
Glover, Robert H.
Green, Thomas H.
Kamitchis, James F.
Ludwick, C. C.
Smith, C. B.
Smith, Francis E.
Stones, J. Eugene
Tesar, Robert M.
Trombla, Lynn B.
Wolff, D. J.
Pauls Valley
Langford, Eldon W.
Ponca City
Athy, L. F.
Crawford, John M.
Hughes, Roland F.
Jordan, C. X.
Mount, E. L.
Prescott, H. R.
Richard, L. J.
Searcy, Frank
Shepherd, Cuth K.
Swan, Bird G.
Vorheis, Byron
Whitehead, L. E.
Prague
Klabzuba, Robert E.
Shawnee
Likens, John P.
McCracken, Guy I.
Rasé, H. L.
Smith, D. F.
Tulsa
Abel, Karl W.
Andrews, H. H.
Arnold, Tapley G.
Austin, Jess W.
Babin, Schley J.
Balbin, Paul D.
Barthelmes, Albert J.
Baum, Robert
Bazhaw, W. O.
Benson, A. E.
Bevan, Thomas J.
Bickel, Harold C.
Bills, Robert N.
Bishop, F. L.
Blakey, Carl W.
Borman, Frank W.
Born, Wm. T.
Boucher, F. G.
Bowie, Duncan M.
Bowman, D. C.
Boyd, Lewis H.
Brannian, Ross E.
Breck, Howard R.
Brown, Henry W.
Bryan, A. B.
Buffum, C. Emery
Campbell, F. F.
Carter, R. W.
Christie, Norman J.
Christy, Robert F.
Clayton, Neal
Cline, A. F.
Cochrane, David M.
Coffin, R. Clare
Connell, Joe E.
Cooley, E. H.
Cooper, Jack R.
Cornett, J. R.
Coryn, F. R.
Crudup, Jack M.
Crump, William W.
Crumrine, Kenneth C.
Cunningham, William J.
Damon, Everett F.
Davis, D. R.
Day, Chas. E.
Dimmick, Opie
Doll, W. R.
Culler, Charles E.
Dyk, Karl
Dzwons, George S.

Edmonson, Carl L.
Egan, Daniel G.
Eisler, Joseph D.
Erdahl, William M.
Evans, Julian F.
Faust, L. Y.
Fearon, R. E.
Ferguson, John L.
Ferris, Craig
Finn, Robert S.
Fishback, Joseph W.
Foster, G. A.
Friendly, Jack L.
Fruehling, S. W.
Garner, J. P.
Garpner, E. U.
Gemmer, R. W.
Gibson, G. D.
Gilkinson, Don
Gilliam, Arthur G.
Gilliam, J. T.
Gilmour, Andrew
Giltinan, G. M.
Giulio, Stanley E.
Green, W. G.
Grimm, G. A.
Handley, E. J.
Harback, Robert G.
Harlton, Bruce H.
Harper, James C.
Hartline, Ralph E.
Harvey, Castle J. C.
Hawes, Julian K.
Hawkins, J. E.
Hays, Clyde L.
Heim, Jean W.
Hill, Sarah Ann
Hoffman, John C.
Hopkins, James S.
Houghton, H. M.
House, A. Maxwell
Hovi, Theodore W.
Hurry, Clare N.
Ingle, G. W.
Innes, Arland I.
Jackson, Judson G.
Jackson, Kenneth
James, Ralph F.
Jameson, Chet, Jr.
Jeffers, Paul H.
Jewell, David F.
Jones, Huston T., Jr.
Jones, V. L.
Kendall, G. D.
Kendall, W. B.
Kezeler, J. L.
Kittredge, F. R.
Koeppel, B. W.
Kundert, Karl H.
Kurk, Edwin H.
Lambert, G. D.
Lambkin, Woodrow W.
Lang, Harold M.
Lash, Charles C.
Lawrence, K. M.
Laws, J. O.
Leas, Mrs. Ruth R.
Leedy, F. B.
Lynn, Ralph D.
Lyons, Paul L.
Manhart, T. A.
Martin, Dick
Mathieson, Raymond L.
Mayes, Tom D.
McAlister, C. H.
McClure, C. E.
McCollum, E. V.
McCready, H. J., Jr.
Mehringer, A. P.
Mitcham, Frank M., Jr.
Moore, Homer C.
Moore, Leland E.
Moore, W. Lee
Mossman, R. W.
Naremore, D. W.
Nash, John M.
Neufeld, J.
Novelly, Walter O.
Officer, Helen V.
Oliphant, Charles W.
Owen, John E.
Page, C. Newton
Pakiser, Louis C.
Palmer, John E.
Patterson, A. R.
Pentecost, Claude D.
Peterson, Glen
Poe, Herbert
Preston, B. G.
Pugh, William E.
Raborn, Smiley, Jr.
Rankin, C. T.
Reed, David E.
Reed, George W.
Reid, A. C.
Rich, J. M.
Richardson, J. W.
Rickel, Wesley K.
Ricker, Norman
Riess, Malcolm
Riley, James K.
Roark, James J.
Roberts, Francis A.
Robertson, K. A.
Robinson, William J.
Rollins, J. C.
Romberg, Marvin
Ross, C. M.
Ross, R. B.
Rupnik, John J.
Rutledge, Richard B.
Schaeffer, Hugh C.
Scherbatskoy, S. A.
Schoellhorn, Henry, III
Scott, C. B.
Seaman, L. O.
Sharpe, Joseph A.
Sibley, W. B.
Silverman, Daniel
Smith, Frank B.
Southgate, Tom F.
Sparks, Neil R.
Stotler, Thomas C.
Stephens, T. V.
Strachan, Clyde G.
Swearingen, A. C.
Sype, William R.
Taylor, Albert
Taylor, Garvin L.
Thomas, T. J.
Thralls, H. M.
Tucker, R. H.
Van Orden, Keene C.
Vernon, Jess
Von Croy, Stefan
Waldrep, W. Day
Walton, James I.
Ward, Dwight E.
Weatherby, B. B.
Weingartner, R. A.
Wells, Wm. M.
Westby, G. H.
Widess, M. B.
Wilkinson, A. L.
Wiliams, P. S.
Wilson, James N.
Winn, Clayton N.
Winnek, J. R.
Woolson, John R.

OREGON

Aurora
Lester, O. C., Jr.

PENNSYLVANIA

Bethlehem
Agocs, W. B.
Bradford
Barber, R. C.
Erie
Wuenschel, Paul C.
New Kensington
Fink, Paul O.
Norwood
Bazzoni, Charles B.
Oakmont
Doolittle, Russell C.
Smith, Douglas H.
Palmerton
McMurray, Howard V.
Philadelphia
Jensen, Homer
Peterson, Eugene F., Jr.
Pittsburgh
Affleck, James
Allon, Michael
Backman, John E.
Bailey, Lothrop H.
Butler, Mark D.
Cerveny, Philip F.
Cook, D. E.

DeWoody, D. A.
Dombart, William F.
Eckhardt, E. A.
Elkins, Thomas A.
Gardner, Louis W.
Gealy, Wendell B.
Gunn, J. E.
Hammer, Sigmund
Herron, Robert C.
Hoylman, H. Wayne
Jones, R. W.
Kilborn, J. M.
Kibby, T. A.
Lamb, William C.
Meszaros, W. A.
Murrell, James T.
Muskat, Morris
O'Donnell, T. J.
Palmer, E. M.
Palmer, Loyal D.
Peters, L. J.
Pezdek, Victor J.
Reiser, Robert C.
Robinson, John L., Jr.
Robinson, W. Bernhard
Texter, John W.
Watson, George R.
Weber, David M.
Wert, Carl M.
Wickerham, M. D.
Wyckoff, R. D.

Ridley Park
Johnson, F. L.

State College
Bacon, Lloyal O.
May, Harold G.
Pirson, Sylvain

Verona
Muffly, Gary

SOUTH DAKOTA

Newell
Jennings, D. Mitchell

TENNESSEE

Oak Ridge
Garrett, George A.

TEXAS

Abilene
McFarland, E. R.
Miller, Nash H.
Olson, Odell C.
Park, Noel R.
Van Siclen, DeWitt C.

Alice
Porter, C. P.

Amarillo
Bruyere, R. N.
Hollis, Jack L.
Moody, N. K., Jr.

Austin
Brown, Leon D., Jr.
Horton, C. W.
Hughes, Darrell S.
Hurt, Worth B.
Lipson, Leonard B.
Mims, R. Lewis
Romberg, Frederick E.

Beaumont
Conklin, Glenn M.
Davis, William W.
Divelbiss, James
Ellis, L. G.
Hollingsworth, W. E.
Konz, Leo W.
McCormack, Harold R.
Millington, John W.
Richert, Bernhard E.
Williams, C. E.
Winterhalter, A.

Beeville
Jackson, R. S.

Bellaire
Barnette, L. Atmar M.
Buckner, Guy O.
Cowles, Laurence G.
Eby, A. N.

Big Lake
Burton, Raiford H.
Bychok, Victor
Nogami, Henry H.

Big Spring
Barnes, Chester F.
Rees, Wesley W.

Birthright
Hargis, A. V.

Breckenridge
Hammial, L. L.
White, S. A.

Cisco
Reeves, James B.

Coleman
Cheney, M. G.

Commerce
Wheeler, Edwin E.

Corpus Christi
Dunbar, R. O.
Howerton, Bert P.
Weatherby, S. P.
Zazvorka, Jerry, Jr.

Crane
Peachee, D. A.

Dallas
Adams, H. R.
Adams, Myron D.
Agnich, Fred J.
Alcock, E. D.
Amis, W. H., Jr.
Andrews, Reagan H.
Arnett, R. D.
Arnold, Kingsland
Autrey, D. W.
Ayres, J. Otis
Batson, James B.
Bean, Robert J.
Bonebrake, Walter C.
Bowler, Gordon E.
Breedlove, Miss Ruth
Brock, Fred A.
Brown, H. Hallock
Browning, K. A.
Burg, K. E.
Bush, James H.
Butt, Harding
Calhoun, F. F.
Campbell, E. L.
Carson, Roe W.
Cathey, John A.
Clewell, Dayton H.
Clifford, O. C., Jr.
Cobb, Howard L.
Coit, R. B.
Collingwood, D. M.
Conover, George E.
Cortes, H. C.
Crump, Oscar M.
Dahm C. G.,
Davidson, George B.
DeFord, H. L.
DeGolyer, E. L.
DeJournette, R. D., Jr.
Dobyns, D. R.
Dodson, Herbert F.
Donnally, Chester J.
Douglas, Norvel
Dugan, Albert F.
Dunlap, Henry F.
Edmonston, William J.
Eichelberger, A. M., Jr.
Fain, Edgar A.
Fetzer, E. L.
Fisk, Frank K.
Gaither, Jerrel
Garrett, M. M.
Gary, J. W.
Gillin, J. A.
Godell, John J.
Granberry, H. E.
Graves, Earl
Gray, Wm. R.
Green, Cecil H.
Gsell, R. N.
Haggarty, Patrick E.
Harkness, T. O.
Henderson, J. B. H.
Henderson, Ross
Heroy, W. B.
Hieatt, Herbert F.
Hightower, C. H.
Hilger, Mrs. C. L., Jr.
Hogg, W. B.
Holbert, Murrell
Horn, J. W.
Isensee, George W.
Jennings, Bruce M., Jr.
Harvey, William P.
Jones, M. P.
Jonsson, J. E.
Karcher, J. C.
Kelsey, Martin C.

Kennedy, Edward P.
Kennedy, Frank H., Jr.
Kern, Jack C., Jr.
Kiesler, Ernest A.
LaNeve, R. O.
Lester, John A.
Linwell, Martin V.
Livingston, E. C.
Lomax, C. J.
MacNaughton, L. W.
Macon, Curtis E.
McBurney, Charles G.
McCain, Hugh, Jr.
McCarver, Holland C.
McDermott, Eugene
McKay, A. E.
McLoad, Kenneth W.
McManus, Jack V.
McMullin, Elbert F.
Menefee, James C.
Minton, J. P.
Mitchell, W. R.
Moody, Herbert
Moog, Richard D.
Moore, F. A.
Moran, Ray O.
Musgrave, Albert W.
Myers, John R.
Nash, Paul E.
Newton, W. W.
Nugent, Roderick M.
Olson, R. W.
Page, John S.
Paslay, L. C.
Payne, J. E.
Pellillo, M. J.
Pernell, J. H.
Perryman, J. D.
Peters, Jack W.
Pittman, C. V. A.
Ransone, W. R.
Reagor, Edward C.
Renner, Darwin S.
Robinson, George W.
Rollins, J. Frank
Roper, W. B.
Rose, H. W.
Russell, Dallas L.
Rust, Carl F.
Sargent, D. M.
Schley, Woodruff H.
Seifert, Wesley H.
Seiler, Geo. E.
Shell, G. N.
Shugart, T. R.
Siegel, Frank
Smiley, W. G., Jr.
Smith, Randolph
Smithwick, H. B.
Sorrels, B. J.
Steel, D. M.
Stehr, Raymond A.
Stulken, E. J.
Swenson, Paul E.
Tabor, E. M.
Teufel, Virgil W.
Thompson, Atlas H.
Thompson, R. P.
Thomsen, Carl J.
Tottenham, W. M.
Travis, Fred L.
Valkus, James W.
Waller, J. A., Jr.
Walton, Britain W.
Walsh, T. N.
Waters, Kenneth H.
Weisbrich, R. A.
White, Gale
Whorton, L. P.
Williams, Charles C.
Williams, Floyd J.
Wissemann, Hilmer J.
Wodrich, Frank W.
Woods, J. P.
Woolley, William C.
Wright, Ray H.

El Paso

Clary, Lawson, Jr.

Ft. Worth

Baird, Walter D.
Dana, R. H.
Davis, Rollin E.
Dudley, Raymond W.
Harris, Sidon
Hollingsworth, W. Wise
Hunzicker, A. A.
Itten, Howard
Johnson, James F.
Kendall, John M.
Kerr, V. Robert
Lang, Ralph H.
Ledyard, Paul H.
Lee, Lynn K.
Long, C. J.
Lovejoy, J. B.
Manns, Anna L.
McLemore, Ethel Ward
Morehead, Jack N.
Morris, James L.
Normand, S. R.
Peabody, Miss Gwendolyn
Sanders, C. W.
Schouten, F. H.
Suggs, M. L.
Thomsen, Erik
Van Steenbergh, S. K.
Warren, Kirby J.
Wilson, John H.

Garland

Stanton, Austin M.
White, R. H.

Grapevine

Deacon, L. E.

Hamilton

Stiles, Miss E.

Houston

Aderman, C. V.
Adler, Joseph L.
Anderson, O. W.
Anderson, John F.
Arthur, M. A.
Bader, Glenn E.
Banta, H. E.
Barbour, P. C.
Barry, Adelbert
Beeman, Keith R.
Beeth, Donald
Bemrose, John
Benke, M. L.
Bennett, Roy F.
Benz, Carl V.
Berg, G. A.
Berndes, A. E.
Bertram, A. C.
Bible, John L.
Black, J. P.
Blau, L. W.
Bolinger, John W.
Bowsky, M. C.
Briard, Vernon E.
Brooks, James A.
Broussard, C. H.
Broussard, D. F.
Brown, Andrew
Brown, Donald R.
Brown, E. E.
Brown, Hart
Bugbee, J. M.
Bunsen, A. W.
Burkhalter, Howard L.
Burnett, A. C.
Butler, W. W.
Byers, John W.
Carlton, Dave P.
Carr, G. W.
Carter, Ray K.
Cash, Harvey, Jr.
Charrin, P. J. D.
Charske, Charles J.
Clark, George B.
Clark, W. C.
Cole, R. C.
Cook, Paul C.
Copeland, R. J.
Crary, Donald
Crowell, J. H.
Culbertson, J. A.
Davis, Donald M.
Deuseen, Alexander
Dodd, Lavon C.
Doll, H. G.
Dunway, J. H.
Dunlap, A. D.
Duty, Robert S., Jr.
Duty, W. B.
Eberts, A. G.
Eby, J. Bryan
Farren, Paul
Feagin, Frank J.
Ferguson, J. B.
Ferguson, Joe L.
Finnigan, Thomas L.

Flude, J. W.
Fohs, F. Julius
Freel, J. F.
Frosch, A.
Frowe, Eugene
Futral, John E.
Gardner, Derry H.
Garrett, W. M.
Gemmill, Edward J.
Geyer, Richard A.
Gibson, Wm. H.
Giezendanner, S. S.
Gilliland, J. R.
Goldstone, Frank
Goss, Henry V.
Grange, Donald C.
Griffin, I. M., Jr.
Griffin, W. Raymond
Guiler, Mona D.
Guyod, H.
Hafner, W.
Hall, T. O.
Hamil, A. B.
Hamilton, W. Brooke
Hamm, J. G.
Happel, Henry H.
Harkins, Curtis P.
Harkins, T. I.
Harrington, George H.
Harris, John
Harris, Phil C.
Hart, M. M.
Haynes, C. J.
Heintz, Karl O.
Henderson, M. R.
Henquet, R.
Herzenberg, A. J.
Hibbler, A. J.
Hibbler, M. E.
Hill, E. Bruce
Hinson, C. C.
Hoard, J. O.
Horvitz, Leo
Hougen, Harold C.
House, H. M.
Hovey, Ivan C.
Howell, Lynn G.
Hubbard, Charles L.
Hubbert, M. King
Hubby, L. M.
Hull, J. W.
Hutchinson, C. C.
Ivy, John S.
Jett, J. E.
Johnson, Frank B.
Judson, Sidney A.
Kannenstine, F. M.
Konkel, Philip M.
Krause, Fred W.
Ladner, A. L.
Lamb, George B.
LaRue, James E.
Lawhorn, O. T.
Lay, Roy L.
Lea, W. T.
LeGrand, J. C.
Leonardon, E. G.
Leverich, Priestley
Lewis, W. B.
Lindsey, R. W.
Locke, Edgar R.
Lowe, C. R.
MacAllister, C. T.
MacMahon, A. M.
Mahannah, Rulon S.
Manes, O. B.
Marr, J. D.
Martin, Jack
Martin, Sidney A., Jr.
Martyn, Phil F.
Matthews, W. A.
McCann, K. G.
McCollum, Burton
McCullagh, John, Jr.
McDonnold, H. W.
McGee, John E.
McReynolds, Gregg F.
Miller, Robert D.
Millet, M. J.
Mitchell, George D., Jr.
Montgomery, J. C.
Morgan, Wesley H.
Morrison, W. D.
Mott-Smith, L. M.
Mounce, W. D.
Mower, L. K.
Neff, W. D.
Nettleton, L. L.
Neuman, L. J.
Newby, C. J.
Nichols, James B.
Noble, Francis H.
Norris, C. G.
Nutt, W. T.
Osterhoudt, W. J.
Palmer, R. L.
Parker, L. A.
Parker, Richard H.
Patrick, H. G.
Pawley, Julian K.
Peacock, H. B.
Peay, L. W., Jr.
Petre, H. D.
Pollard, J. C.
Pranglin, John A.
Raines, Eli
Randolph, J. R.
Ray, Robert H.
Reed, Chas. F.
Reed, Paul C.
Reynolds, F. F.
Reynolds, Robert D.
Robinson, Edwin H.
Rogers, Austin S.
Rogers, R. M.
Rolshausen, F. W.
Roos, Lewis V.
Rosaire, E. E.
Rumsey, Paul T.
Rusch, Peter J.
Ruska, Walter
Rust, W. M., Jr.
Sappington, Chester
Sargent, R. L.
Sauls, James L.
Saville, W. G.
Schafer, Sidney
Schmidt, Henry
Schmuck, R. H.
Schofield, G. A.
Scholl, Louis A., Jr.
Schumacher, J. P.
Scott, D. L.
Selig, A. L.
Sharp, C. Sheldon
Sheets, Martin M.
Sherer, E. S.
Sherar, Stuart
Shimek, E. J.
Shore, Harold F.
Sims, Sam E.
Slotnick, M. M.
Smith, A. L.
Smith, J. Angelo
Smith, Noyes D.
Somers, George B.
Steele, W. E., Jr.
Stewart, S. B.
Stockton, Frank, Jr.
Stone, George B.
Stratton, Everett F.
Swartz, Charles A.
Sweet, R. C.
Taylor, Josiah
Taylor, W. Harlan
Terry, Melvin C.
Terry, Russell D.
Tucker, Robert L.
Unger, Earle E.
Upshaw, R. W.
Urban, L. M.
Van Auken, John A.
Van Melle, F. A.
Vreugde, L. M. H.
Wallace, C. R.
Ware, J. H.
Watt, J. S.
Weatherburn, K. R.
Weaver, Paul
Whitsitt, C. D.
Wilber, Roscoe C.
Williamson, Lonnie C.
Wingett, R. O.
Winter, A. B.
Winter, George W.
Wolf, Alexander
Woods, Archie G.
Yates, Miss Cal
Yeates, F. L.
Yokobaitis, A. C.
Zavoico, Basil B.
Zenor, H. M.

Zimmerman, C. C.
Zirbel, N. N.

Jacksboro
Cooke, Raymond F.
Owings, B. F.

Kermit
Spencer, Samuel A.

Kingsville
Porter, Hugh

Lamesa
Kerbow, R. B.

Laredo
Jett, Glendon D.

Levelland
Heard, James R.
Kelsch, Raymond L.

Livingston
Jackson, G. L.

Longview
Lohse, John M.

Lubbock
Conant, E. E.
Epperson, R. S.
Feather, V. G.
Klaus, Hellmut
Morrison, M. S.
Penney, A. B.

Maypearl
Thomas, E.

McAllen
Harris, B. A.

Mexia
Wise, J. B.

Midland
Arick, M. B.
Bradley, H. W.
Durham, Charles A.
Forward, Fred
Gibson, M. O.
Jackson, O. B.
Jasper, Walter E.
Long, G. J.
McKinsey, M. H.
Park, Lee B.
St. Clair, D. W.
Shock, Lorenz I.
Uhrig, Leonard F.
Winter, Niles B.

Miller Grove
Gore, Robert F.

Ozona
Head, E. I.

Palacious
Sisson, H. H.

Palestine
Williams, Richard

Pampa
Gallie, J. F.

Pecos
Ruhlen, W. W.

Perryton
Kunkel, T. L.

Riverside
Weinzierl, J. F.

Rosenburg
Foote, W. L.
Myers, Charles E.
Neese, U. E.

San Angelo
Keller, Raymond F.
Moore, Arthur A., Jr.
Thomas, J. W., Jr.

San Antonio
Allen, Thomas L.
Barbisch, J. B.
Bennett, Elwin
Crawford, Paul D., Sr.
Crawford, W. L.
Davis, L. A.
Dawson, Herbert M.
DeLoach, E. L.
Donnelly, V. T.
Hemmi, C. W.
Homan, W. L.
Imle, John F.
Kelley, W. W.
Kohler, A.
McDaniel, C. M., Jr.
Moore, Marion J.
Narvarte, P. E.
Palmer, Ernest
Parr, J. D., Jr.
Petty, Dabney E.
Petty, O. S.
Petty, Van A., Jr.
Pratt, R. B.
Roberts, Homer E.
Roberts, Louin W.
Rudolph, P. J.
Schmidt, K. H.
Smitherman, Lynn A.
Snow, Leland
Souther, J. B.
Tucker, Bill C.
West, Thomas S.
Wright, J. Dexter

Sherman
Schiflett, H. L.

Sinton
LaRue, W. W.

Sudan
Kelley, Clovis C.

Sugar Land
Starr, A. G.

Three Rivers
Dexter, Lawrence N.

Tivoli
Zagst, Edward F.

Tulia
Graham, Burleson

Tyler
Albertson, Miss Dorothy E.
Brooks, O. D.
Tefft, Gerald H.

Vernon
Mills, Frank

Waxahachie
Shackelford, Lewis L., Jr.

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Montgomery, Geo. P. Jr.

Wichita Falls
Bradley, Joe R.
Crain, Robert A.
Maxey, J. R.
Mayfield, W. I.
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Yoakum
McGuckin, Glenn M.

UTAH

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Watson, James M.

Salt Lake City
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VIRGINIA

Alexandria
Lipson, Edward

WASHINGTON

Seattle
Etherington, T. J.

Spokane
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WISCONSIN

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Woodard, Dan H.

WYOMING

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Burton, Gerald A.
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Fenwick, Willis H.
Hohag, Walton H., Jr.
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Klett, Richard C.
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Parker, John M.
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Schombel, L. F.
Tucker, M. D.
Van der Weg, Klaas
Walczak, Michael J.
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Winfrey, D. B.
Woodruff, Charles Robert

Gillette
Fillippone, W. R.

Lander
Williams, E. D.

Laramie
Courtney, C. J.
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Lusk
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Rawlins
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Worland
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FOREIGN

ARABIA

Dhahran, Saudi Arabia
Storm, Alfred E.

BELGIUM

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Evrard, Pierre

BRITISH WEST INDIES

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Trinidad
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CUBA

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Nottinghamshire

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Sagoci, Hilmi F.
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